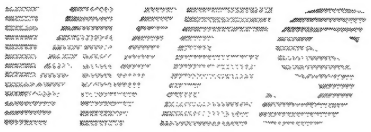
Contract Report GL-98-2
February 1998

US Army Corps of Engineers
Waterways Experiment Station

A Study of Near-Source Earthquake Ground Motions of Three California Earthquakes: Northridge, Whittier, and Landers

by David J. Leeds



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Prepared for Headquarters, U.S. Army Corps of Engineers

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by David J. Leeds

David J. Leeds and Associates
11972 Chalon Road
Los Angeles, CA 90049

Final report

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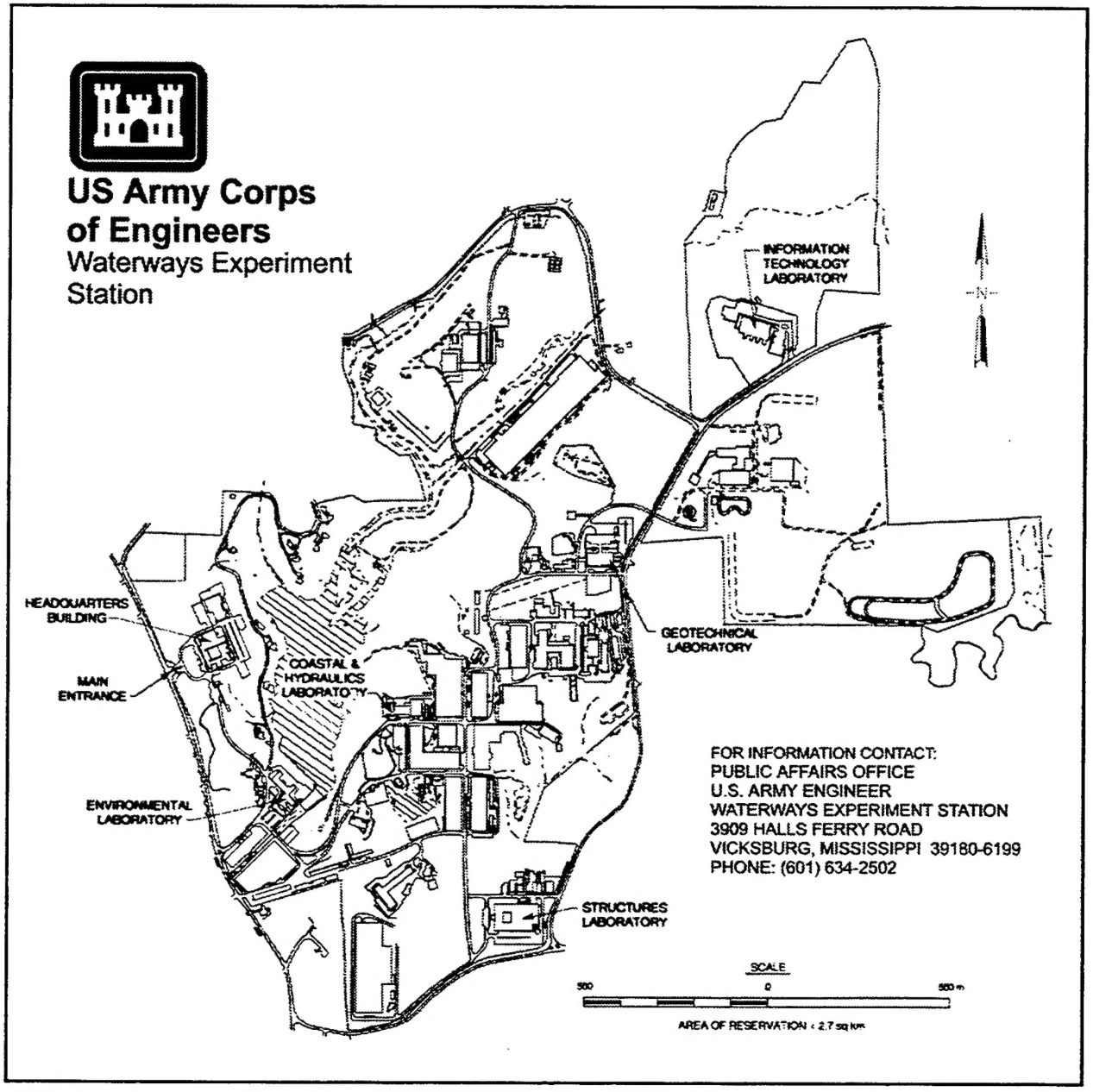
3909 Halls Ferry Road, Vickburg, MS 39180-6199



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Preface

This report was sponsored by the U.S. Army Corps of Engineers in the Army Civil Works Earthquake Engineering Research Program (EQEN). This study is part of ongoing EQEN research regarding geological-seismological evaluation of earthquake hazards.

The report was prepared by Mr. David J. Leeds, Consultant, Los Angeles, CA, under contract No. DACW39-96-M-1349 and was monitored by the Geotechnical Laboratory (GL), U.S. Army Engineer Waterways Experiment Station (WES). Dr. W. F. Marcuson III was Director, GL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Robin R. Cababa, EN.

Foreword

This report should be utilized with the following points in mind.

- Site conditions at the majority of strong-motion accelerograph stations are poorly known, even to the operators of the stations. Geologic and geotechnic parameters of many of the stations used in this report are derived from gross geologic maps and may be hopelessly inadequate. Some few however are known with great detail. No qualitative evaluation of the site classifications are given.

- Maximum accelerations from many of the stations are unprocessed (Vol. I) values. Later publications may slightly change the values.

- There is debate with respect to the use of maximum acceleration as an index of damage potential. Consideration has been given to an "effective" acceleration wherein high frequency peaks are clipped, as well as the use of maximum velocity as a parameter.

- Epicenter locations, depths of focus, and magnitudes may vary dependent upon reevaluation of the data, as well as data set used. Menlo Park, Pasadena, and Berkeley may differ slightly in their calculations. The differences are not significant to this study.

- Fault locations, specially buried thrust faults, are still in a state of flux. The scales used preclude precise locations. The scheme used is the most recent released by the Southern California Earthquake Center (SCEC).

- The contouring program used leaves decisions outside the control of the operator. That is, there is no personal bias in any of the contouring.

- The reader must carefully scrutinize the data to evaluate the site characteristics of the recording station. All stations are used in these plots, from freefield to second basement.

- New ideas are continually emerging. Geomorphic control of ground shaking and the effect of pressure ridges (Reidel ridges) have only recently been recognized.

Problem:

Earthquake ground motion, in engineering terms, usually has only a single descriptor: maximum peak horizontal acceleration. The acquisition of large suites of near-source ground motion data and developing analyses suggests the utility of further exploitation of the data.

Current practice has failed to recognize the effect of strong vertical motions, a weakness demonstrated by the many column failures in the recent Northridge Earthquake. Also, there has not previously been as large a suite of strong-motion records where this component had such high values.

Earthquake mechanisms, site conditions, and topography are important and must be considered. There are also differences between basement and nearby freefield recordings which require compatibility adjustments of basement records where freefield recordings are not available.

Isoseismal maps traditionally plot only the reported intensity. This report utilizes the large suite of recorded accelerations, plotting both the recorded as well as "adjusted" data. The adjustments have the effect of "leveling the playing field," providing more stations suitable for ground motion studies.

Historical Horizontal Accelerations:

Acceleration recordings began in late 1932 in the Los Angels area of Southern California under the auspices of the U.S. Coast and Geodetic Survey. Even these earliest accelerograms indicated that peak ground motions were greater than the design levels used by engineers. As the years passed and more instruments were fielded, higher and higher accelerations were recorded. The most significant event at which near-source ground motions were "captured" was the Norhridge Earthquake of January 17, 1994. Exploitation of these data, and their application to engineering design, is essential. Table HHA shows this increase of horizontal recorded ground motion over time:

TABLE HHA. HISTORICAL HORIZONTAL ACCELERATIONS

Date	Earthquake	Mag.	Dist (km)	Site	Horizontal Accel, g
1933	Long Beach	6.2	10	Soft	0.19
1940	El Centro	7.1	9	Soft	0.33
1966	Parkfield	5.6	31	Soft	0.48
1971	San Fernando	6.5	9	Rock	1.15
1980	Mammoth Lakes	6.3	14	---	0.99
1984	Morgan Hill	6.2	25	Franciscan	1.29
1985	Nahanni, Canada				0.91
1987	Whittier	5.9	1	Firm	0.54
1992	Cape Mendocino	7.1	4	Rock	>1.8
1992	Landers/Big Bear	6.5	11	Al/Gn	0.57
1993	Coalinga, Aft.				0.82
1994	Northridge	6.7	5	Soft	1.82

Historical Vertical Accelerations:

Vertical acceleration recordings have also increased in values with time, but their effect has forcibly been brought to our attention only recently. See Table HVA.

TABLE HVA. HISTORICAL VERTICAL ACCELERATIONS

Date	Earthquake	Mag.	Dist (km)	Site	Vertical Accel, g
1971	San Fernando, Pacoima Dam	6.5	9	Rock	0.72
1976	Gazli, USSR	7.3	10?	Hard	1.30
1978	Tabbas, Iran	7.4	3	Soft	0.88
1979	Imp. Valley: Sta.6	6.6	1	Soft	1.74
1980	Mexicali Vict. Sta	6.4	0	Soft	1.00
1985	Nahanni, NWT	6.9	8	Hard	>2.00
1992	Landers, CA	7.5	22	Soft	0.20
1992	Petrolia, Cape M.	7.1	4	Rock	>1.85
1994	N'ridge, Tarzana	6.7	5	Al/Si	1.18
1994	N'ridge, Pac. Dam	6.7	17	Rock	1.40

These tables, and the lists of less well known earthquakes, show that large motions are not isolate events but are common to the epicentral areas of shallow focus earthquakes of magnitudes approaching 6 and over.

Other Studies:

Several published articles or reports are germane to the present report (see References). Isoseismal (intensity) maps of the Northridge earthquake have been published by Dewey et al. (1995). Borcherdt (ms.1994) displayed a horizontal isoacceleration map in early 1994. Horizontal isoacceleration maps have been published by Stewart et al. (1995). Preliminary isoacceleration maps, both horizontal and vertical using USC data only, were published by Todorovska et al. (February 1994). The data of Borcherdt (USGS) and of Todorovska (USC) were available to the present study. The papers by Dewey et al. and by Stewart et al. were published after our plots were complete.

Procedure:

- Task 1: Isoacceleration maps have been prepared for three recent, large Southern California Earthquakes:
  Northridge, January 17, 1994
  Landers, June 28, 1992
  Whittier, October 1, 1987.
  The isoseismal maps have been prepared using the as-reported (raw) data for horizontal and vertical components of motion, and with several iterations making adjustment for site conditions, freefield/basement/structure relationships, and response to NEHRP criteria. Values for the individual points have been processed to accommodate these influencing factors.

- Task 2: The final isoacceleration maps are overlain on structural geologic maps with recent fault locations.

- Task 3: Interpretation considers the following:

  Recording site conditions

  Horizontal and vertical motions with respect to magnitude, fault types, and distance from fault sources

  Spectral content and predominant period

  Scaling to possible larger and smaller earthquakes

Report:

The report presents our conclusions with respect to fault mechanisms, earthquake magnitudes, distance from sources, and site conditions.

Representative horizontal and vertical accelerograms with their spectra are presented.

Personnel:

The study was conducted by David J. Leeds, Principal. Assistance in computer contouring was by Dr. Larry Porter. We are also indebted to Mr. Tom Solemio (formerly of ANCO Engineers) for other computer assistance. There has been consultation with other prominent geologists/seismologists in interpretation and fault locations.

Schedule:

Delays were encountered in the acquisition of certain of the strong-motion data. There was a long delay for important Northridge Earthquake records. Many of the "Code" stations as of the date of this report are still not available. The "Code" stations for the City of Los Angeles have not routinely been collected. Some have recovered by the California Division of Mines and Geology and other contractors. Their targets for completion of this project have not been met; however, we believe there is sufficient data to finalize the database.

Database:

Suites of strong-motion accelerograph records from three recent Southern California earthquakes have been selected for analysis. The Northridge Earthquake provides the best data by far, both in the levels of motion and the quantity of data. Quality with respect to recording and data processing is satisfactory and uniform for all stations. Landers data is a bit weak in terms of nearfield stations, and Whittier does not have a large magnitude. However, this is what nature has provided.

Northridge	January 17, 1994	Ms = 6.6	34.211°N	118.538°W
Landers	June 28, 1992	M = 7.5	34.201°N	116.436°W
Whittier	October 1, 1987	ML = 6.1	34.058°N	118.075°W

TABLE I-R

Structural adjustment (multiplier).
Adjusts recording from structure to freefield.

1.0 Freefield to 3-story building (gnd/bsmt location).
1.4 4-story to high rise (ground/basement location).

These "constants" were derived from an examination of the dozen pairs of freefield/structure sets of records. There is some scatter, but a reasonably constant relationship exists between recordings at ground or basement level within the structure, and the nearby freefield record.

TABLE I-S

Site adjustment to convert to equivalent rock site:

S	Soft	Multiply by 0.6
F	Firm	Multiply by 0.8
H	Hard	Multiply by 0.9
R	Rock	Multiply by 1.0

These relationships were derived from examination of recordings at similar distance but with varying surficial geotechnical/geological conditions. Applying these adjustments converts all observations to an equivalent rock site.

TABLE I-Z

NEHRP (National Earthquake Hazards Reduction Program) site adjustments:

Converted as a multiplier of recorded motion by factors shown to normalize to "A", rock. Factor is acceleration dependent. See Geotechnical Reference.

	NEHRP	This report	Acceleration, g 0.1g	0.2g	0.3g	0.4g	0.5g
Hard Rock	A_o	AO	1.25	1.25	1.25	1.25	1.25
Rock	A	AA	1.00	1.00	1.00	1.00	1.00
Very stiff/gravels	B	BB	0.83	0.83	0.91	1.00	1.00
Sand, silt, clay	C	CC	0.62	0.71	0.83	0.91	1.00
Thin clay	D1	D1	0.40	0.59	0.83	1.11	1.11
Thick clay	D2	D2	0.50	0.62	0.83	1.11	1.11
Problem sites	E	EE	----	----	----	----	----

Vertical/Horizontal Ground Motion Ratios

The data for the three earthquakes has been examined with respect to the ratio of vertical to maximum horizontal acceleration. Values for each individual station are shown in Column **AQ** on the master spread sheets, Table I. The ratios in radial zones centering on the epicenters follows:

Northridge:	**km, radius**	**No. stations**	**v ÷ H**
	0-10	11	0.82
	11-25	50	0.61
	0-25	61	0.65
	26-50	81	0.50
	0-50	142	0.56
	51-100	199	0.40
	0-100	341	0.54
Whittier:	**km, radius**	**No. stations**	**V ÷ H**
	0-10	18	0.70
	11-25	33	0.58
	0-25	51	0.62
	26-50	58	0.67
	0-50	109	0.65
	51-100	75	0.50
	0-100	184	0.59
Landers:	**km, radius**	**No. stations**	**V ÷ H**
	0-25	4	0.84
	26-50	15	0.79
	0-50	19	0.80
	51-100	143	0.64
	0-100	162	0.66

Recommendations:

Of the three datasets used, the Northridge has by far the best potential for exploitation. Several obvious recommendations present themselves.

- Is the complete network of almost 375 stations in the Los Angeles area Necessary? Discounting the special studies such as on highway structures, bridges, certain types of buildings, and hospitals, can the same data be obtained by fewer or relocated stations? It is recognized that each of the several networks or systems was derived with different objectives. The present compilation combines all of the published data and much unpublished data.

Since both freefield and structural data are mixed, examination should be continued to establish a confidence level for the use of structural data in ground-motion studies. Are the factors used in this report acceptable? What is acceptable? What records from different types of structure can be equated with freefield?

Each of the several types of instrumental locations should be plotted separately to examine variation of recorded motion due to location in a structure.

Each of the three major network datasets should be independently plotted and compared. Once a confidence level is ascribed to the structural stations, then redeployment of some of the freefield stations should provide improved coverage.

- Past geological/geotechnical evaluations have tended to lump stations into a few categories, with "alluvium" hiding a host of variations. Also, location with respect to buried thrust faults and Reidel folds has not been a consideration. Recognition, and targeting, of these three conditions is a necessity if we are ever able to understand near-source ground motion.

- Much more needs to be known about instrumental site conditions. This need not require deep borings and geophysics for every site. Our knowledge of sites has not kept up with the proliferation of instrumentation. The expense of instrumentation of one major structure (approximately $50,000) is about the cost of adequate preliminary site descriptions of about 200 stations. It would certainly raise the confidence level in the use of accelerograph data.

- A comprehensive (combined) catalogue of strong-motion stations is required, and assignment of standard code names to each station. This is the norm for teleseismic stations but not for strong motion.

Conclusions

1. Vertical motion is enhanced in the near-source area of high angle thrust faults such as in the Northridge earthquake.

2. Short range variation of ground motion may be explained in areas of youthful, geomorphic/tectonic folds by the effect of Reidel ridges. These areas undergoing stress exhibit higher shaking than nearby sites and are indicative of nearby active faulting.

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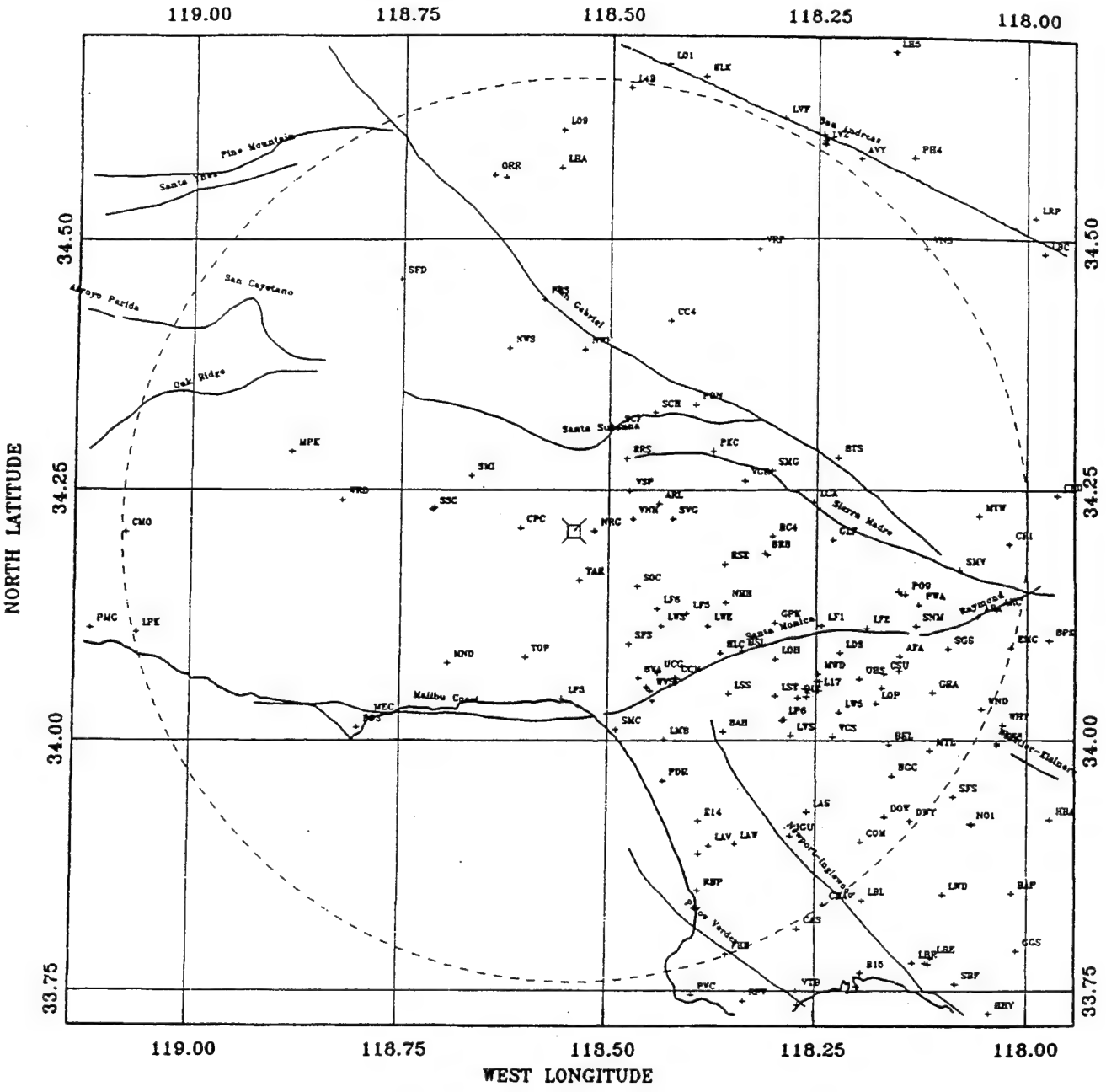
Note: Additional data has been supplied by Roger Borcherdt (U.S. Geological Survey), Mihailo Trifunac and Maria Todorovska (University of Southern California), Ron Tognazzini (Los Angeles Department of Water and Power), and Dennis Ostrom (Southern California Edison Company).

Group 1. Named Faults and Stations

Fig. NRDG-50
Fig. NRDG-100

Fig. WHIT-50
Fig. WHIT-100

Fig. LAND-50
Fig. LAND-100



Northridge Earthquake M=6.7 Main Shock of January 17, 1994

Stations with Maximum Horizontal Records

RADIUS OF CIRCLE IS 50 KM

Stations – total: 348, with data: 344, without: 4, rejected: 0, in plot: 198

Map File: CALINE2.DAT
Command File: NR50HZ.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: NRDGDIS.PRN
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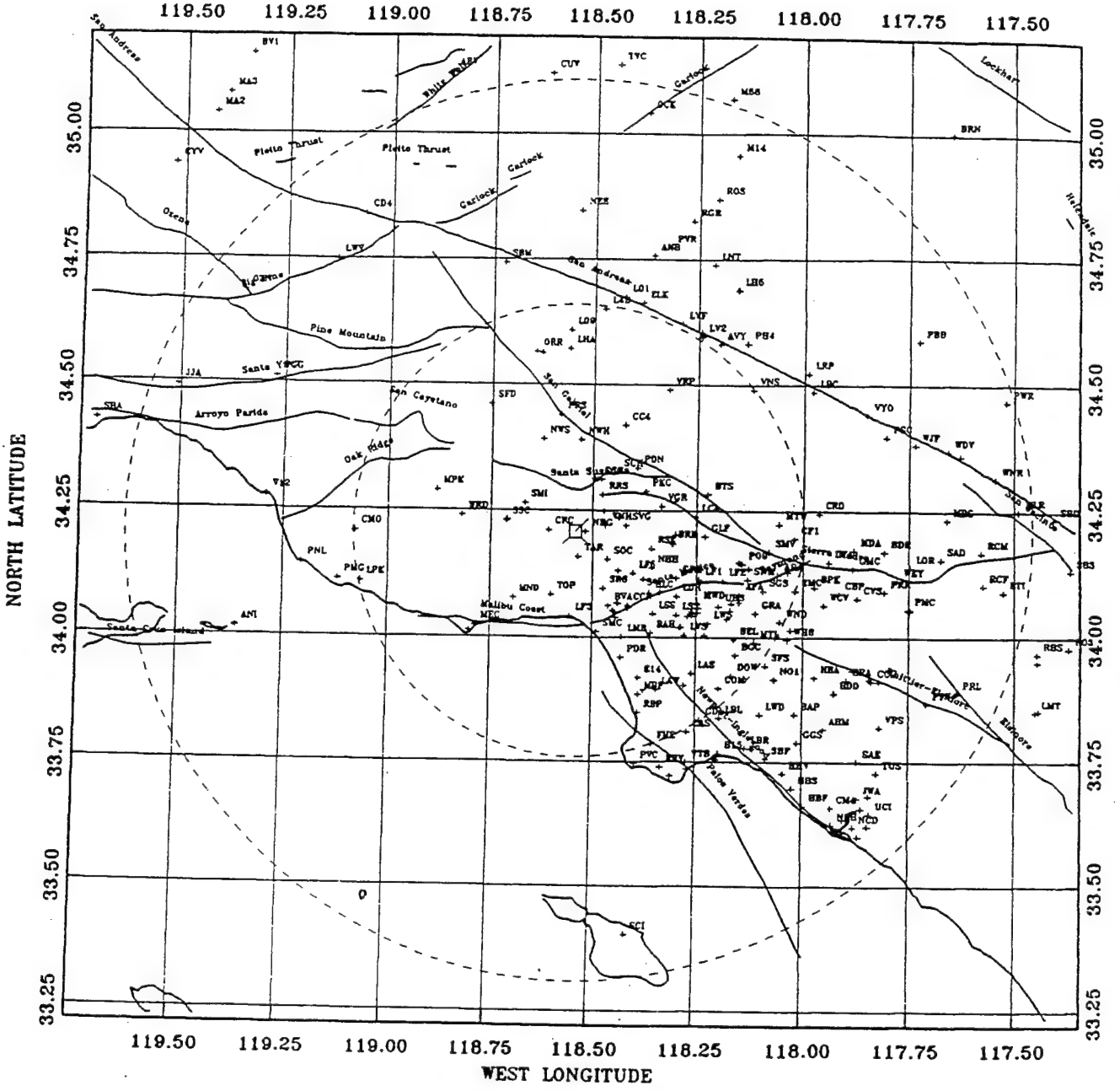
Fig. NRDG-50



Northridge Earthquake M=6.7 Main Shock of January 17, 1994

Stations with Maximum Horizontal Records

RADIUS OF LARGEST CIRCLE IS 100 KM

Stations – total: 348, with data: 344, without: 4, rejected: 0, in plot: 301

Map File: CALINE1.DAT
Command File: NR100HZ.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: NRDGDIS.PRN
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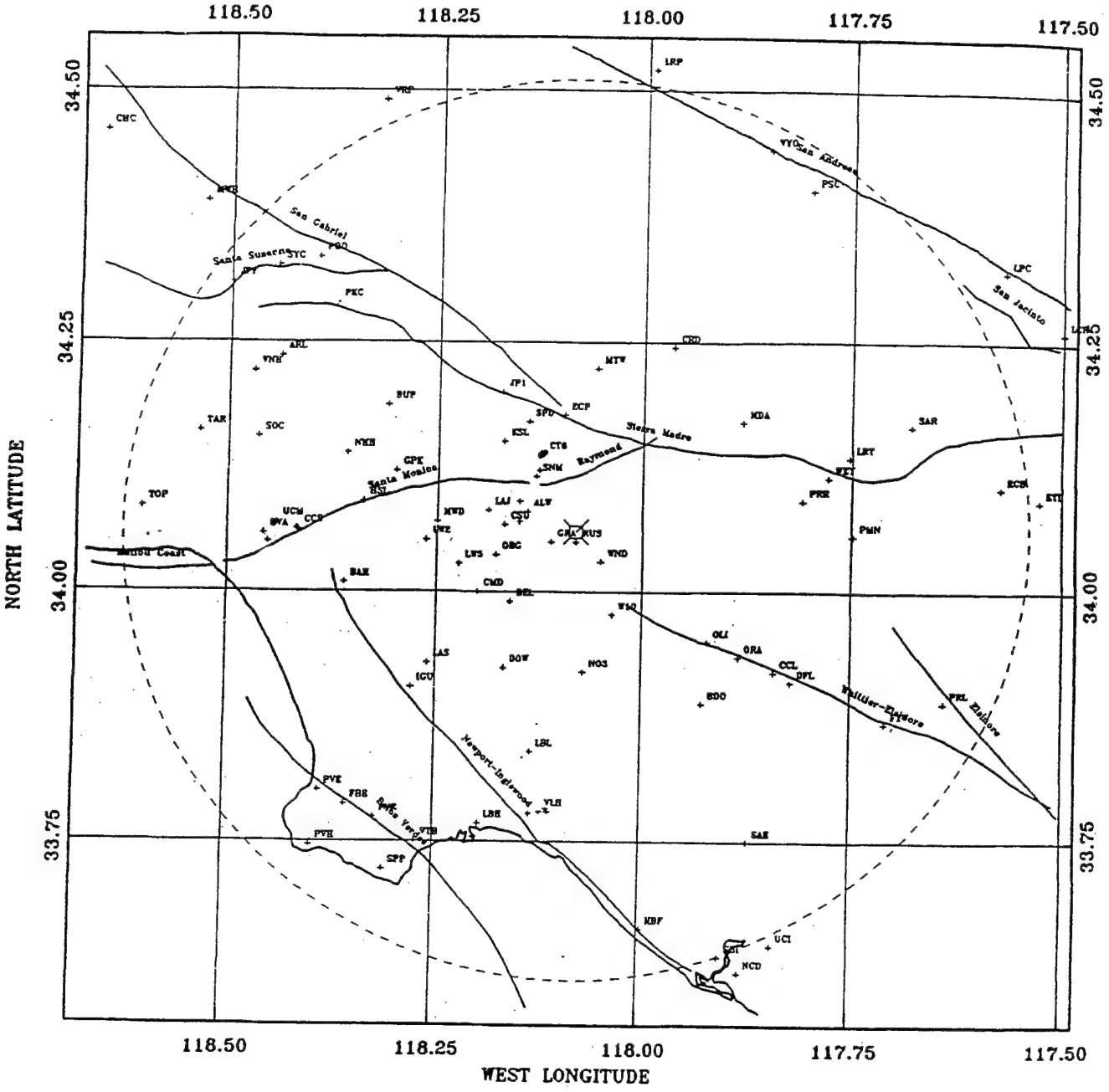
Fig. NRDG-100



Whittier Earthquake M=5.9 of October 1, 1987

Stations with Maximum Horizontal Records

RADIUS OF CIRCLE IS 50 KM

Stations – total: 184, with data: 184, without: 0, rejected: 0, in plot: 116

Map File: CALINE2.DAT
Command File: WH50HZ.GAC
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Fault File: KANAMN.DAT

Station File: WHITDIS.PRN
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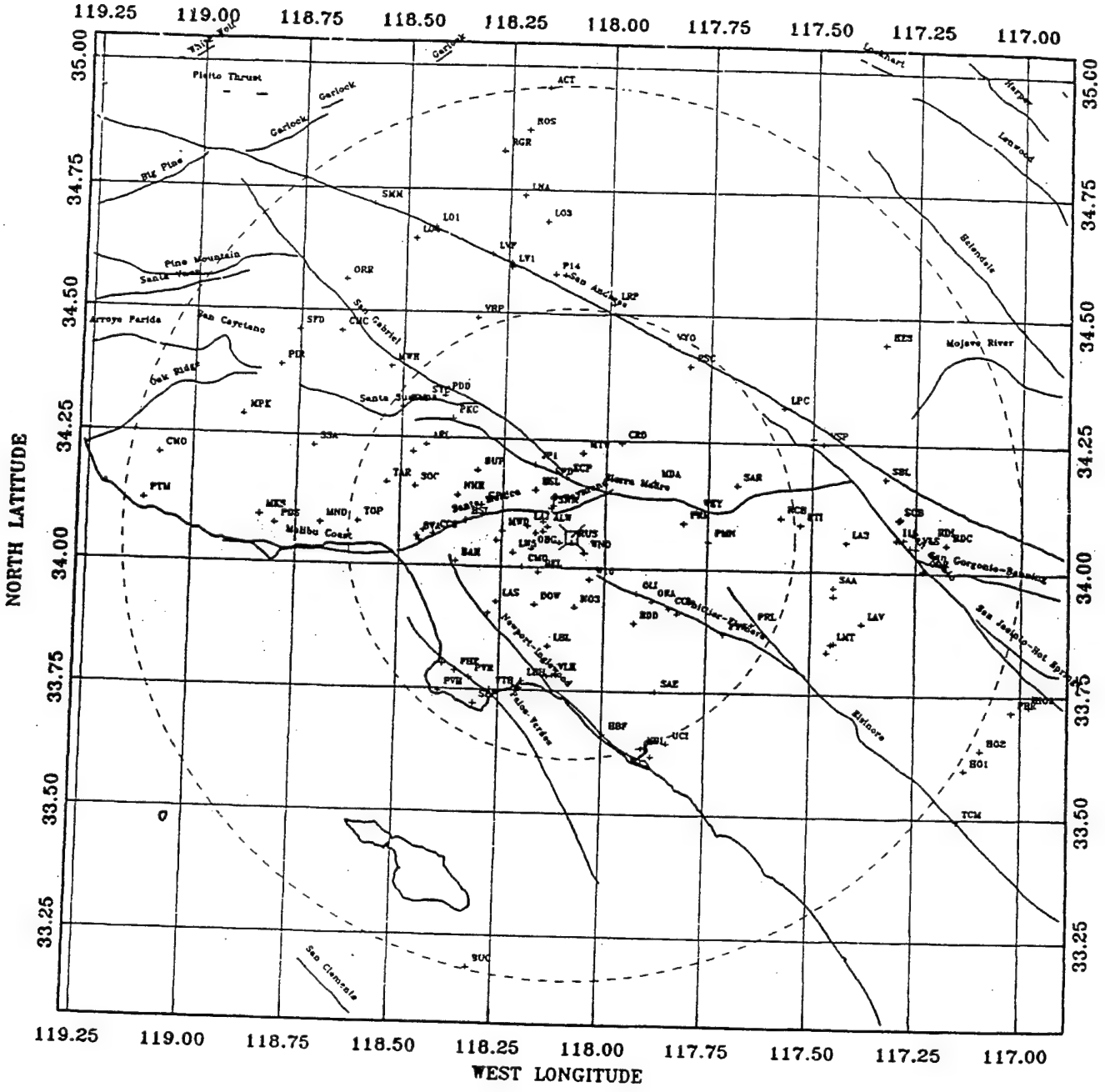
Fig. WHIT-50



Whittier Earthquake M=5.9 of October 1, 1987

Stations with Maximum Horizontal Records

RADIUS OF LARGEST CIRCLE IS 100 KM

Stations – total: 184, with data: 184, without: 0, rejected: 0, in plot: 181

Map File: CALINE2.DAT
Command File: WH100HZ.CAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: WHITDIS.PRN
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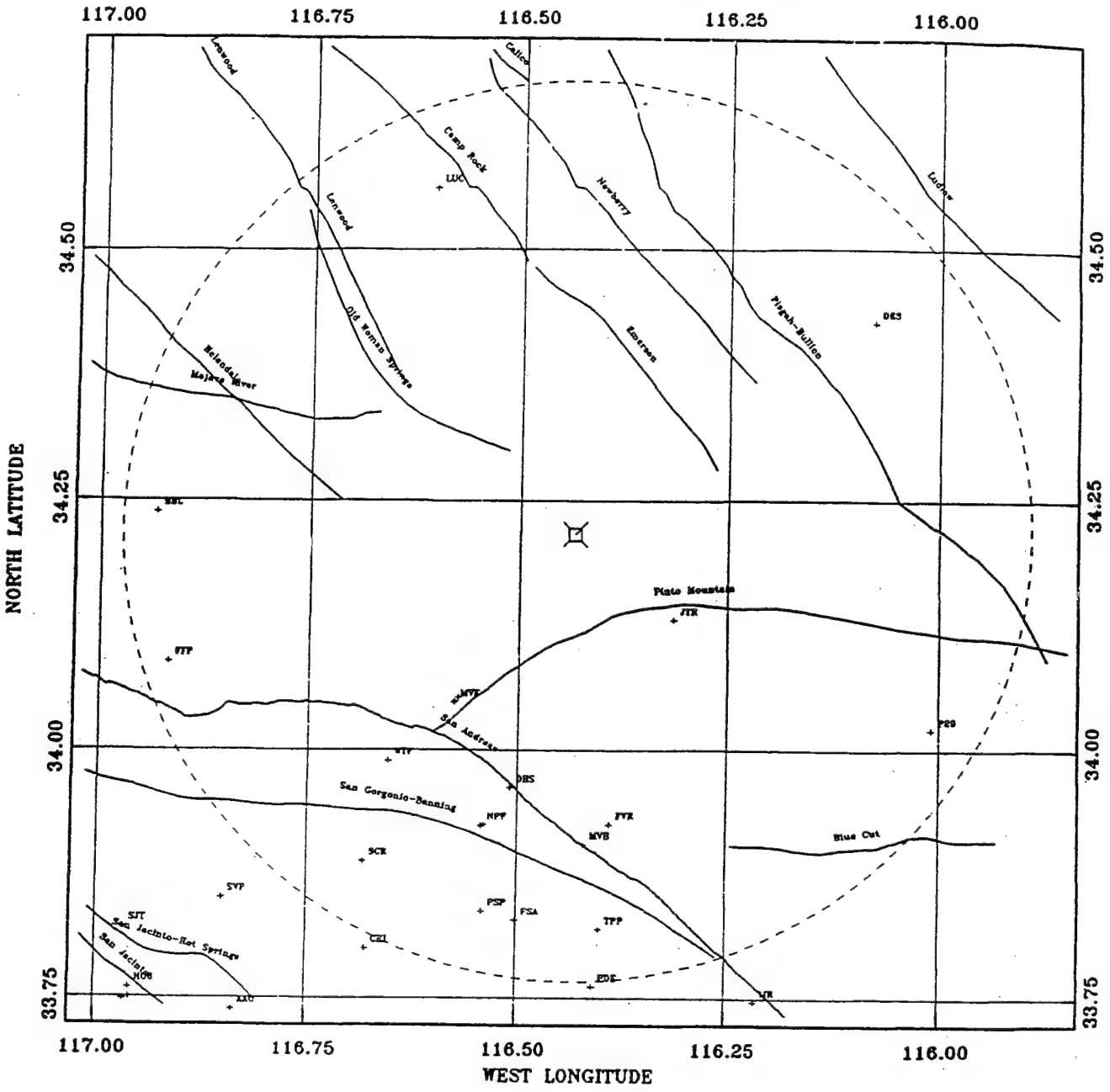
Fig. WHIT-100



Landers Earthquake M=7.5 of June 28, 1992

Stations with Maximum Horizontal Records

RADIUS OF CIRCLE IS 50 KM

Stations – total: 162, with data: 162, without: 0, rejected: 0, in plot: 28

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Command File: LN50HZ.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: LANDDIS.PRN
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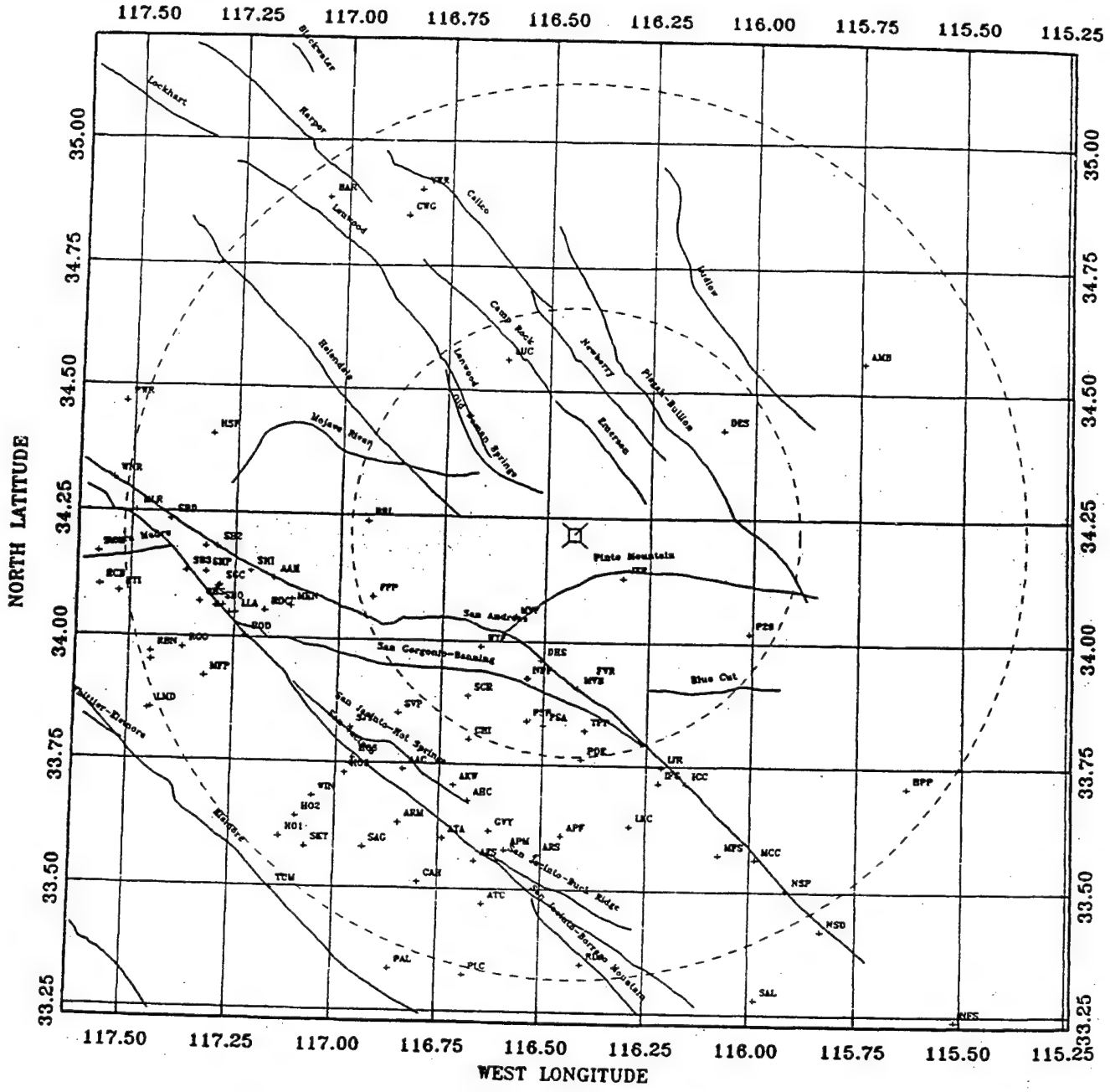
Fig. LAND-50



Landers Earthquake M=7.5 of June 28, 1992

Stations with Maximum Horizontal Records

RADIUS OF LARGEST CIRCLE IS 100 KM

Stations – total: 162, with data: 162, without: 0, rejected: 0, in plot: 108

Map File: CALINE2.DAT
Command File: LN100HZ.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: LANDDIS.PRN
(Lambert conformal projection)
1995 MAY 22 01:31:27.44

Fig. LAND-100

Group 2. Ground Motion

Fig. NRDG-50-NS (Col. M)
Fig. NRDG-50-V (Col. N)
Fig. NRDG-50-EW (Col. O)
Fig. NRDG-50-MAX (Col. P)

Fig. NRDG-100-V (Col. N)
Fig. NRDG-100-MAX (Col. P)

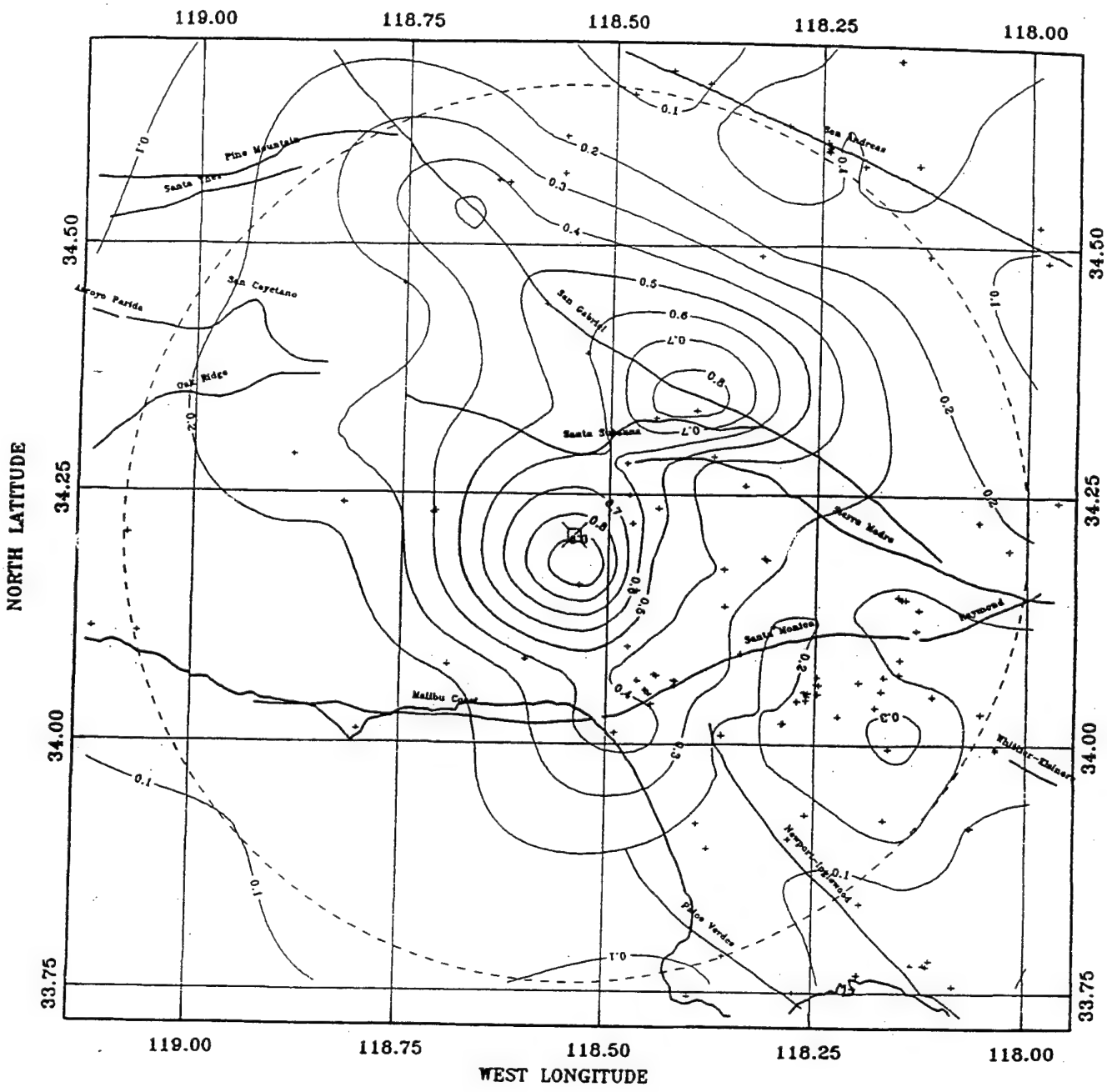
Fig. NRDG-50-NS W/O TAR
Fig. NRDG-50-V W/O TAR
Fig. NRDG-50-EW W/O TAR
Fig. NRDG-50-MAX W/O TAR

Fig. WHIT-50-NS (Col. M)
Fig. WHIT-50-V (Col. N)
Fig. WHIT-50-EW (Col. O)
Fig. WHIT-50-MAX (Col. P)

Fig. WHIT-100-V (Col. N)
Fig. WHIT-100-MAX (Col. P)

Fig. LAND-50-NS (Col. M)
Fig. LAND-50-V (Col. N)
Fig. LAND-50-EW (Col. O)
Fig. LAND-50-MAX (Cl. P)

Fig. LAND-100-V (Col. N)
Fig. LAND-100-MAX (Col. P)



Northridge Earthquake M=6.7 of January 17, 1994

Maximum North-South Acceleration

RADIUS OF CIRCLE IS 50 KM

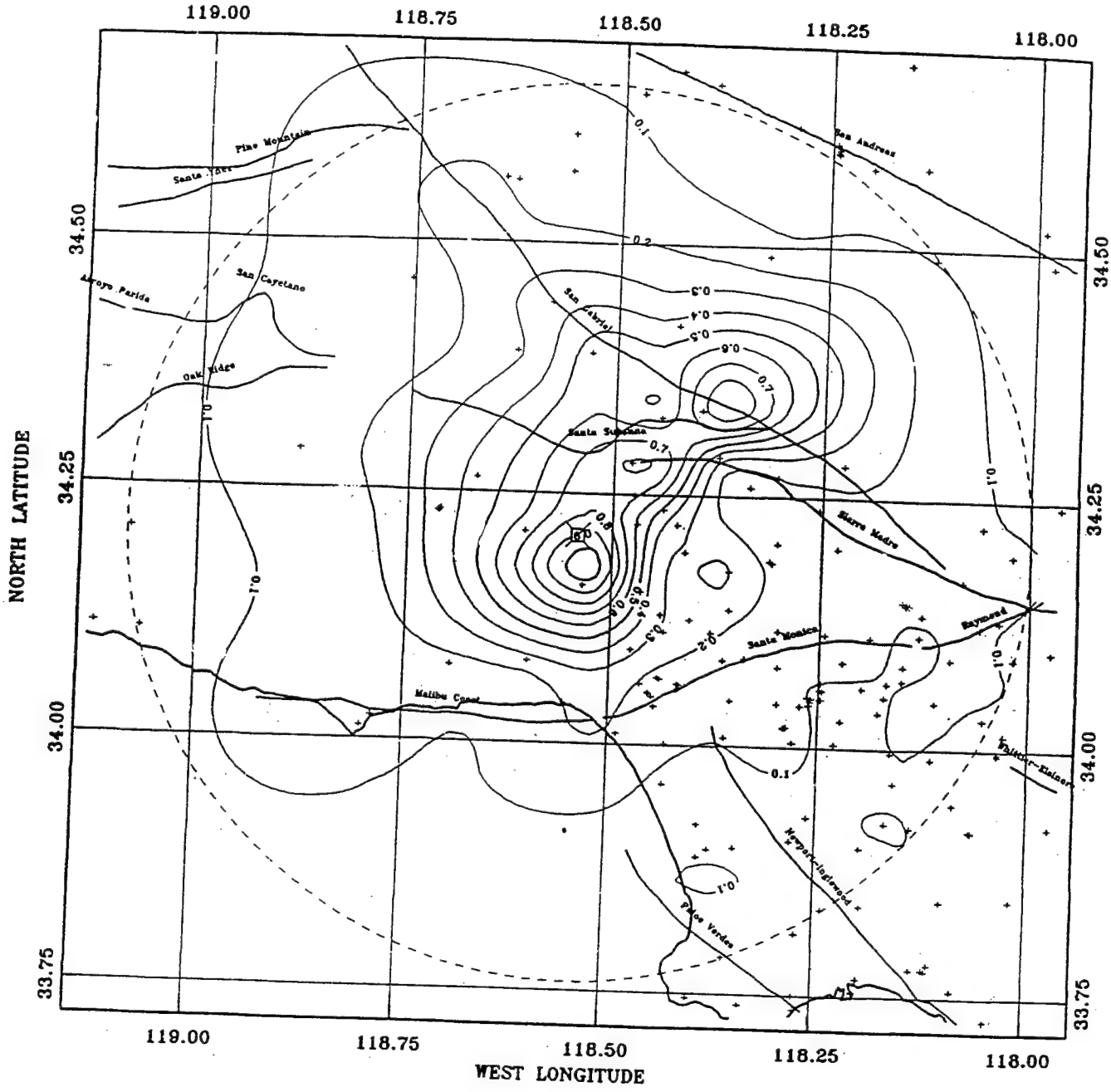
Stations – total: 348, with data: 280, without: 68, rejected: 0, in plot: 144

Map File: CALINE2.DAT
Command File: NR50NC.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: NRDGDIS.PRN
(Lambert conformal projection)
1995 MAY 22 04:13:43.47

Fig. NRDG-50-NS (Col. M)



Northridge Earthquake M=6.7 of January 17, 1994

Maximum Vertical Acceleration

RADIUS OF CIRCLE IS 50 KM

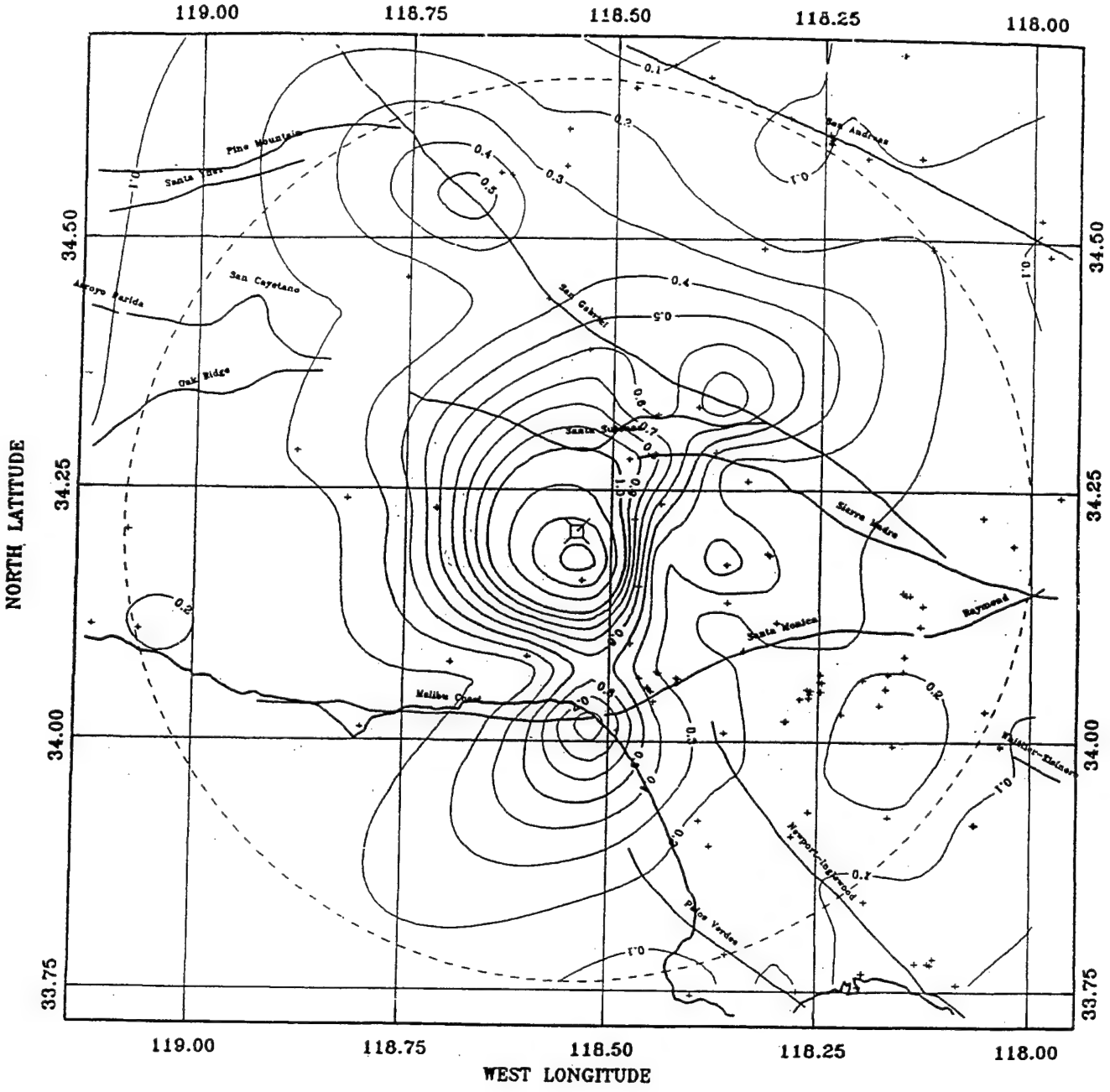
Stations – total: 348, with data: 344, without: 4, rejected: 0, in plot: 197

Map File: CALINE2.DAT
Command File: NR50VC.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: NRDGDIS.PRN
(Lambert conformal projection)
1995 MAY 22 04:14:44.72

Fig. NRDG-50-V (Col. N)



Northridge Earthquake M=6.7 of January 17, 1994

Maximum East-West Acceleration

RADIUS OF CIRCLE IS 50 KM

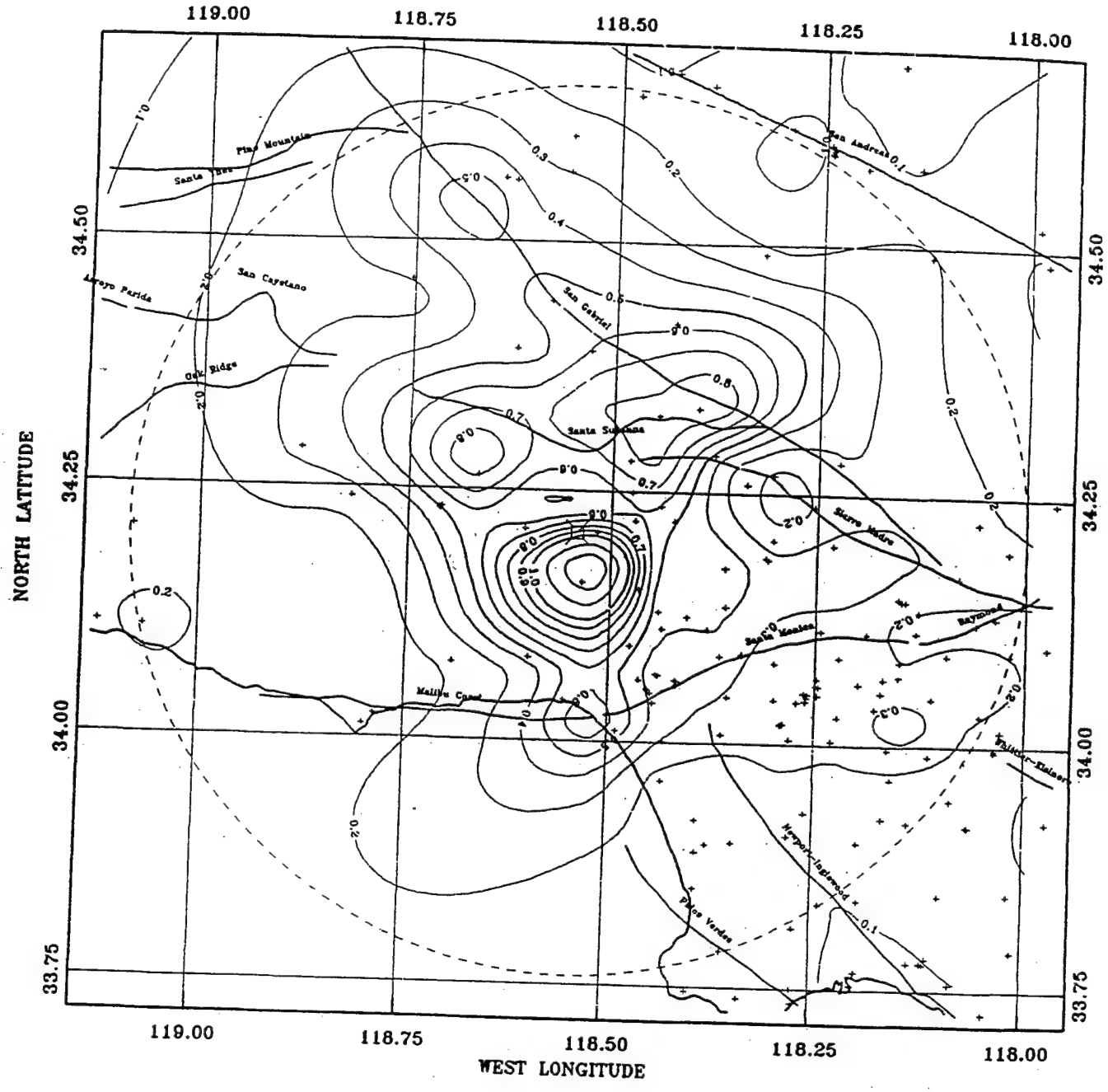
Stations – total: 348, with data: 278, without: 70, rejected: 0, in plot: 143

Map File: CALINE2.DAT
Command File: NR50EC.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: NRDGDIS.PRN
(Lambert conformal projection)
1995 MAY 22 04:16:25.89

Fig. NRDG-50-EW (Col. 0)



Northridge Earthquake M=6.7 of January 17, 1994

Maximum Horizontal Acceleration

RADIUS OF CIRCLE IS 50 KM

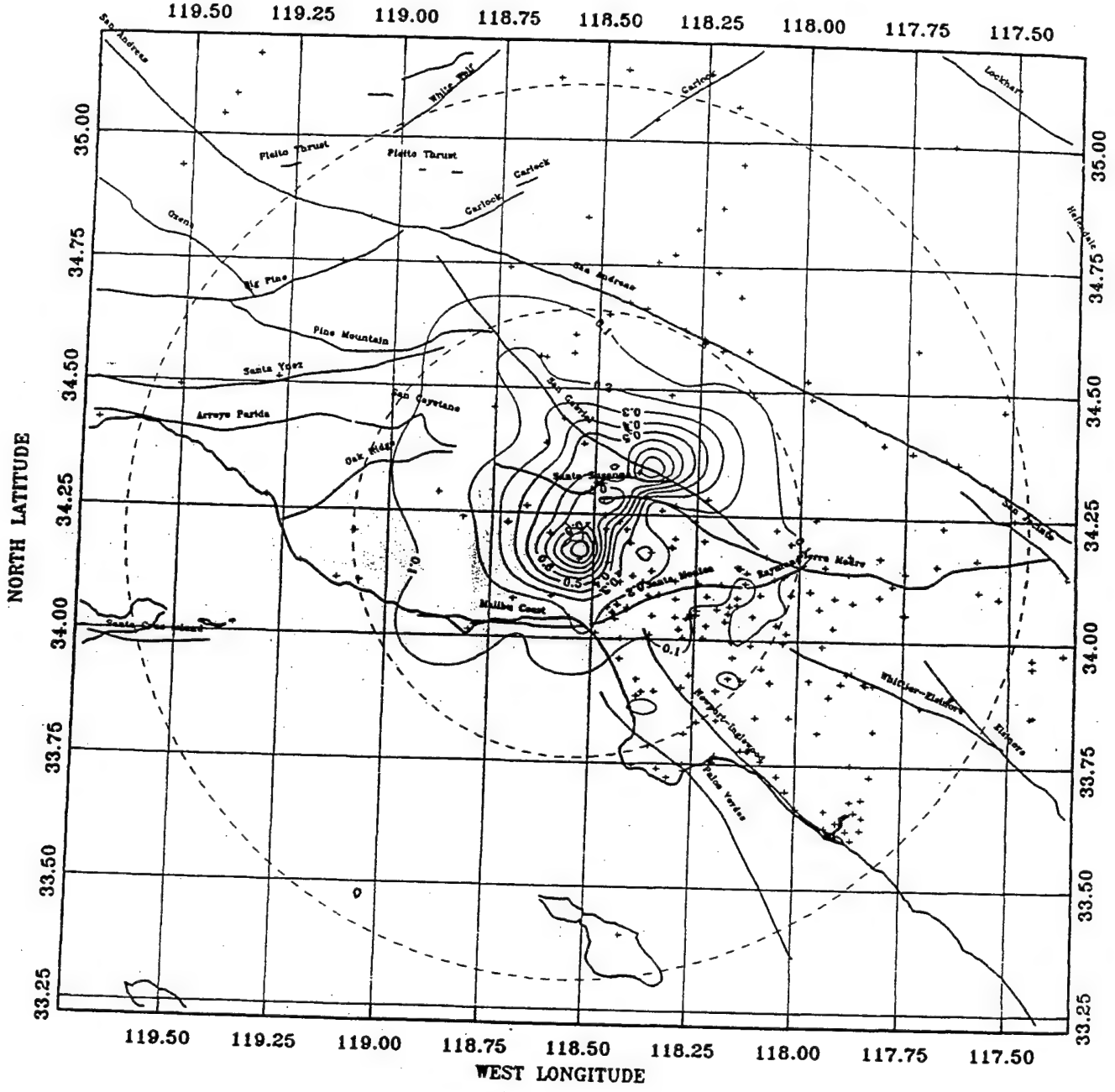
Stations – total: 348, with data: 344, without: 4, rejected: 0, in plot: 198

Map File: CALINE2.DAT
Command File: NR50HC.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: NRDGDIS.PRN
(Lambert conformal projection)
1995 MAY 22 04:17:34.44

Fig. NRDG-50-MAX (Col. P)



Northridge Earthquake M=6.7 of January 17, 1994

Maximum Vertical Acceleration

RADIUS OF LARGEST CIRCLE IS 100 KM

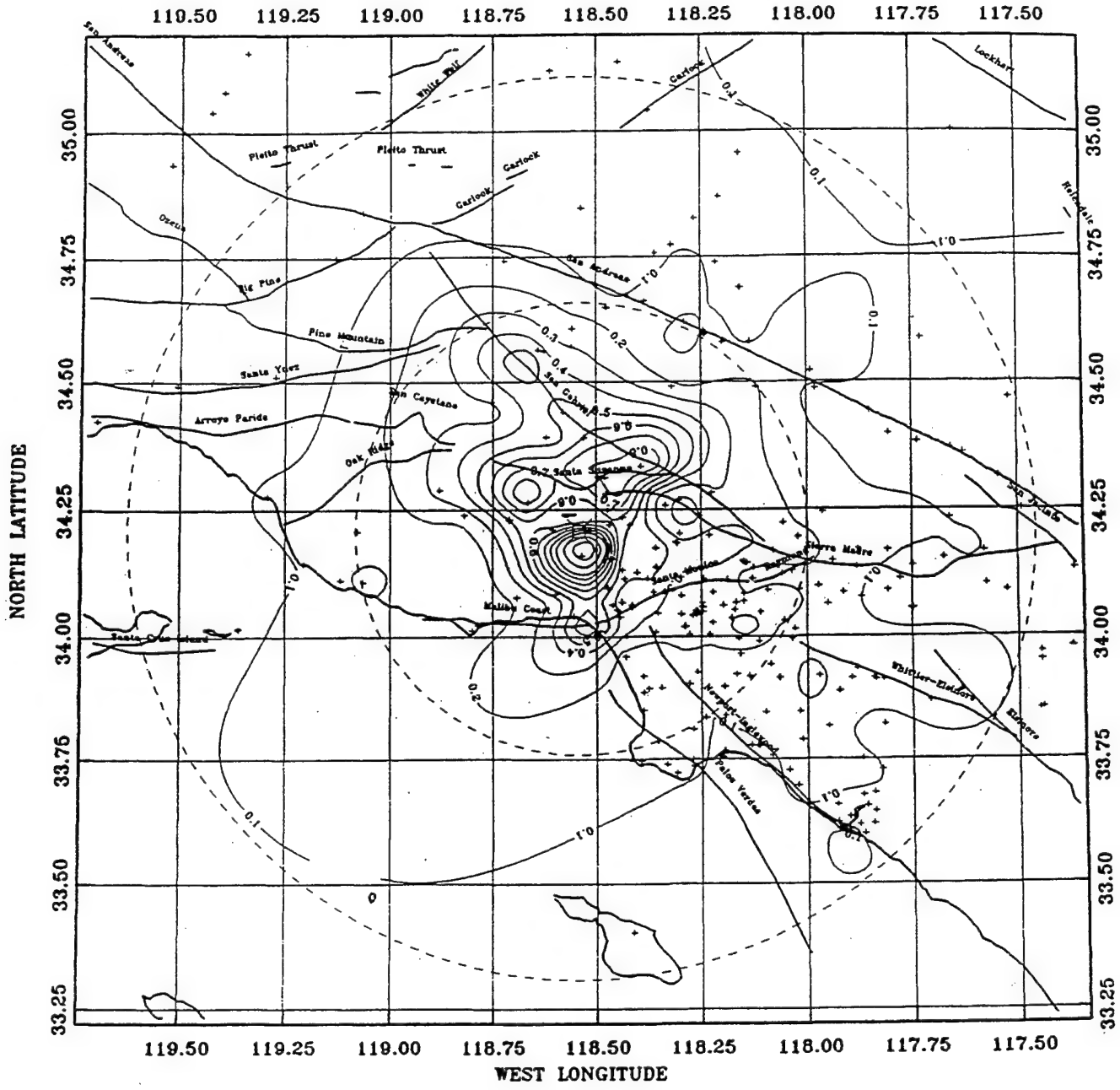
Stations – total: 348, with data: 344, without: 4, rejected: 0, in plot: 301

Map File: CALINE1.DAT
Command File: NR100VC.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: NRDGDIS.PRN
(Lambert conformal projection)
1995 MAY 22 04:20:54.20

Fig. NRDG-100-V (Col. N)



Northridge Earthquake M=6.7 of January 17, 1994

Maximum Horizontal Acceleration

RADIUS OF LARGEST CIRCLE IS 100 KM

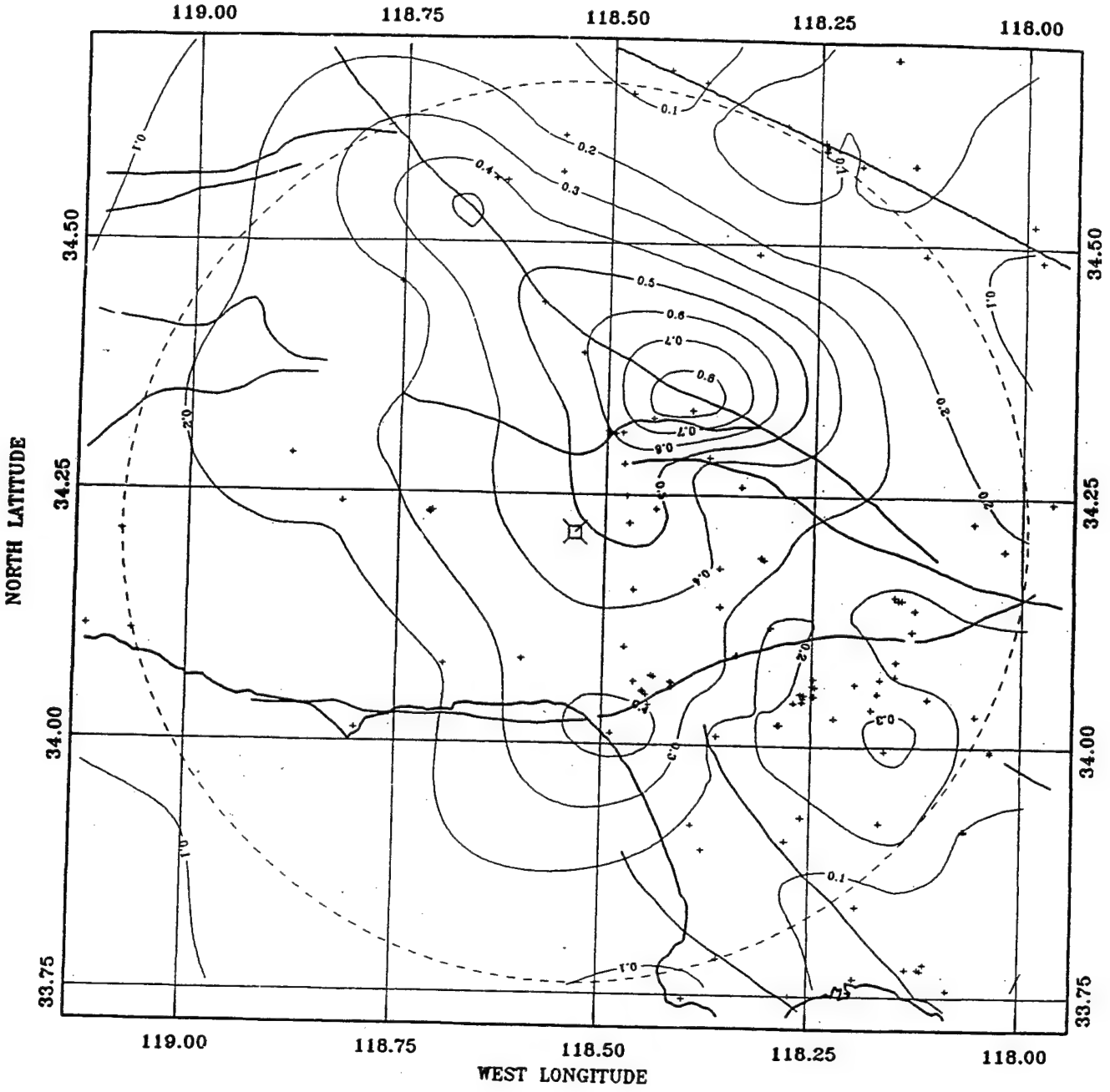
Stations - total: 348, with data: 344, without: 4, rejected: 0, in plot: 301

Map File: CALINE1.DAT
Command File: NR100HC.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: NRDGDIS.PRN
(Lambert conformal projection)
1995 MAY 22 04:24:15.83

Fig. NRDG-100-MAX (Col. P)



Northridge Earthquake M=6.6 of January 17, 1994

North-South Acceleration (w/o TAR), g

RADIUS OF CIRCLE IS 50 KM

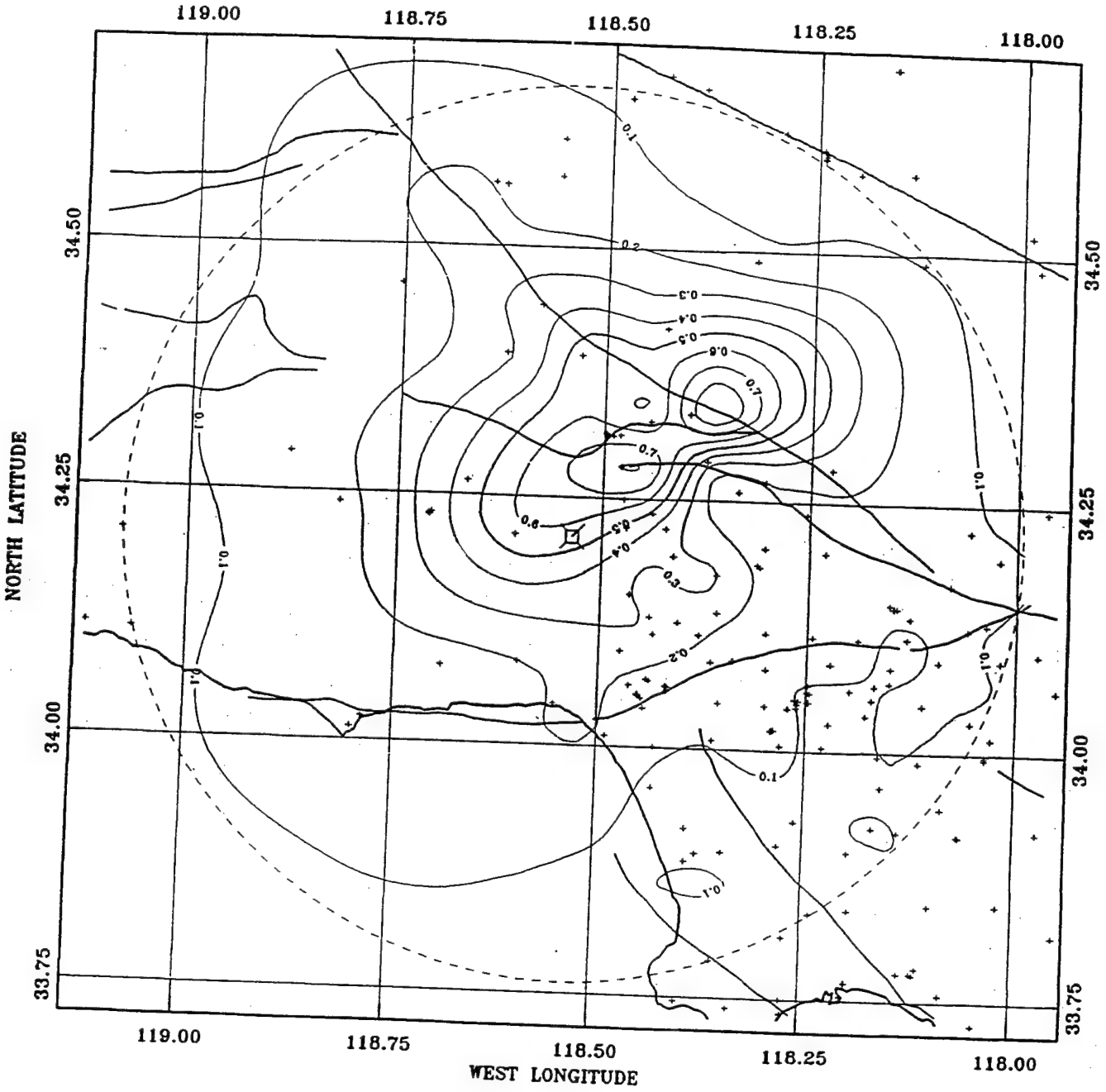
Stations – total: 348, with data: 279, without: 68, rejected: 1, in plot: 143

Map File: CALINE2.DAT
Command File: NR50NWT.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: NRDGDIS.PRN
(Lambert conformal projection)
1995 MAY 28 18:10:57.01

Fig. NRDG-50-NS w/o TAR



Northridge Earthquake M=6.6 of January 17, 1994

Vertical Acceleration (w/o TAR), g

RADIUS OF CIRCLE IS 50 KM

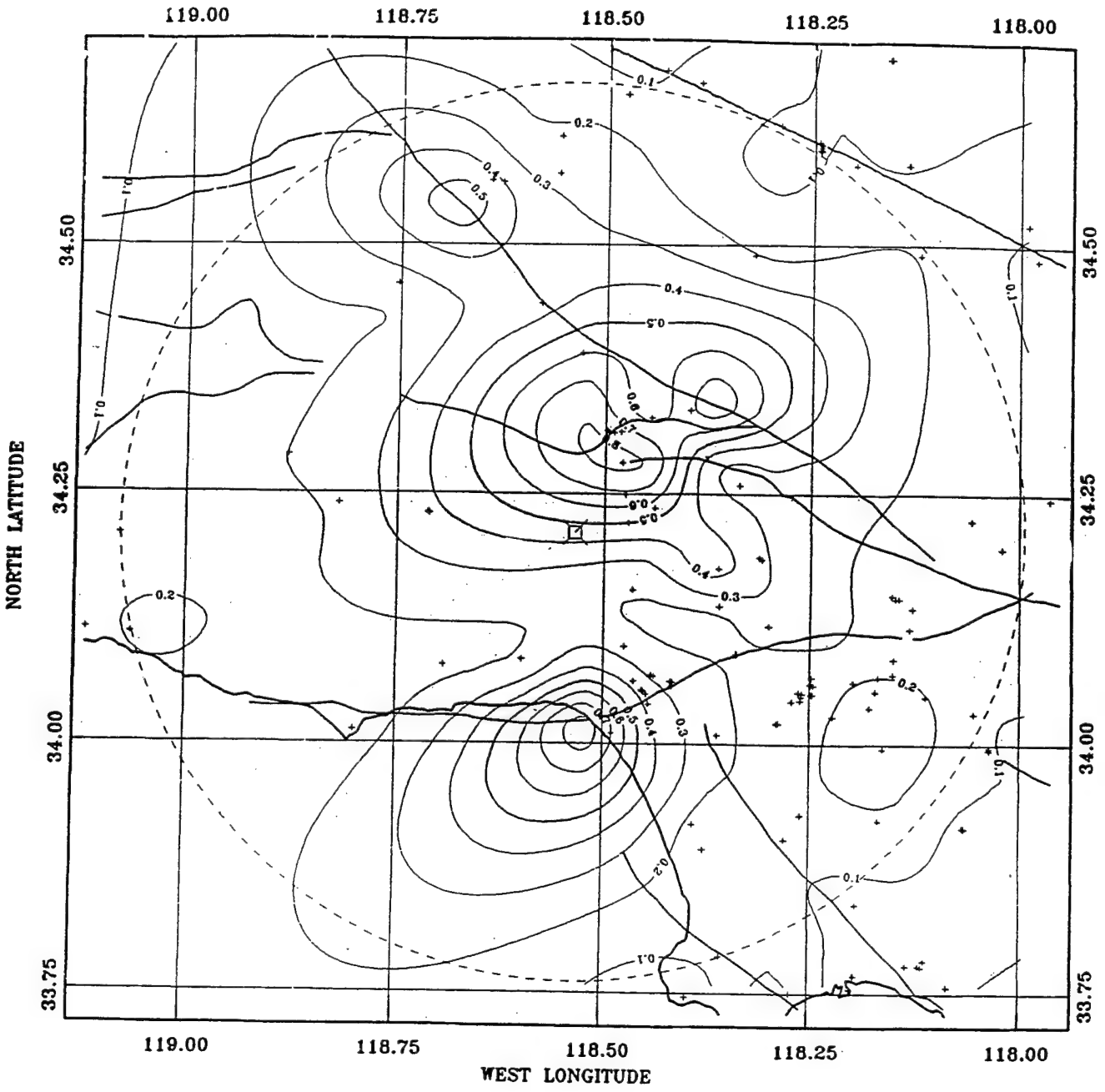
Stations – total: 348, with data: 343, without: 4, rejected: 1, in plot: 198

Map File: CALINE2.DAT
Command File: NR50VWT.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: NRDGDIS.PRN
(Lambert conformal projection)
1995 MAY 28 16:11:53.15

Fig. NRDG-50-V w/o TAR



Northridge Earthquake M=6.6 of January 17, 1994

East–West Acceleration (w/o TAR), g

RADIUS OF CIRCLE IS 50 KM

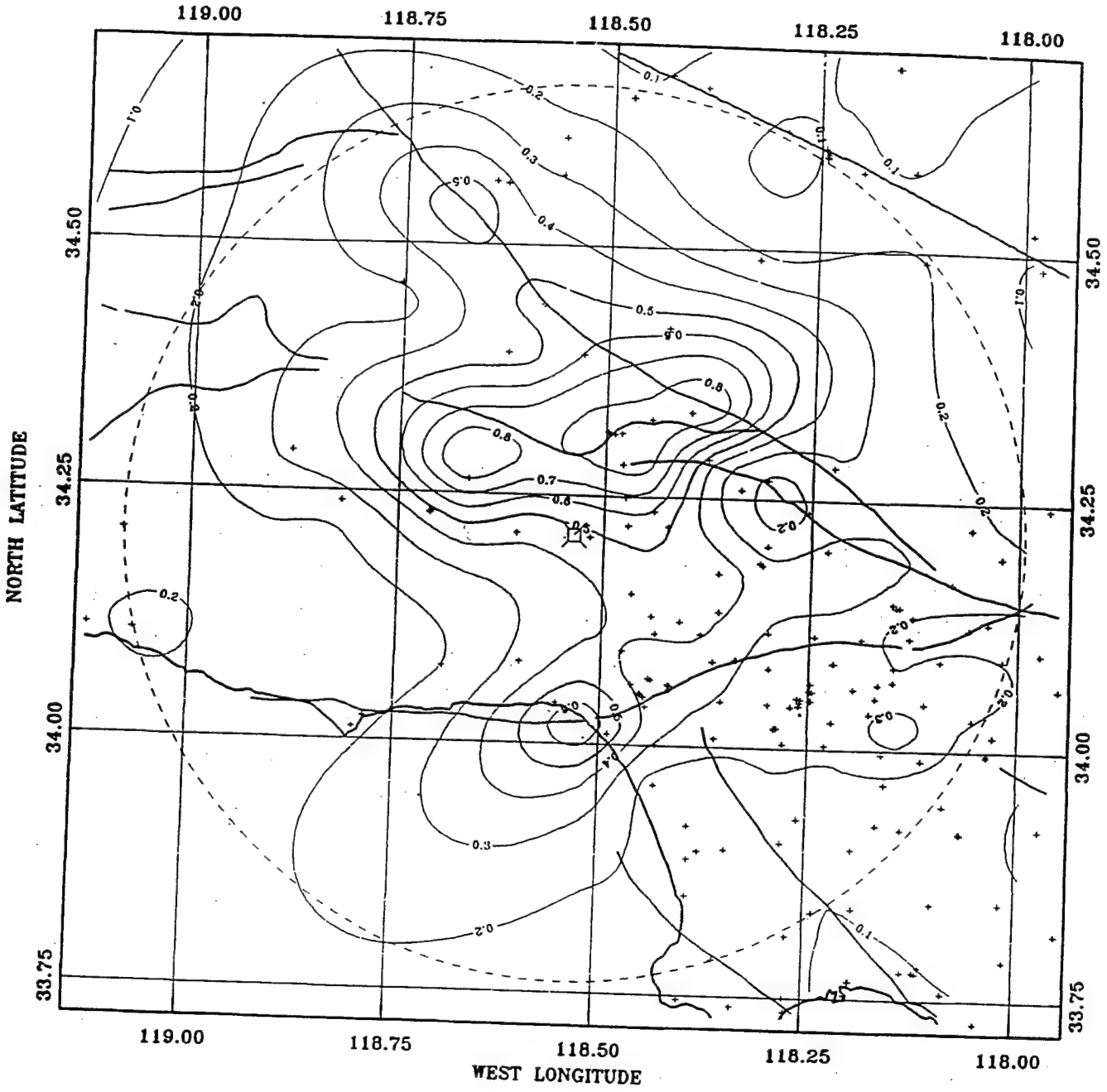
Stations – total: 348, with data: 277, without: 70, rejected: 1, in plot: 142

Map File: CALINE2.DAT
Command File: NR50EWT.CAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: NRDGDIS.PRN
(Lambert conformal projection)
1995 MAY 28 18:12:50.10

Fig. NRDG-50-EW w/o TAR



Northridge Earthquake M=6.6 of January 17, 1994

Maximum Horizontal Acceleration (w/o TAR), g

RADIUS OF CIRCLE IS 50 KM

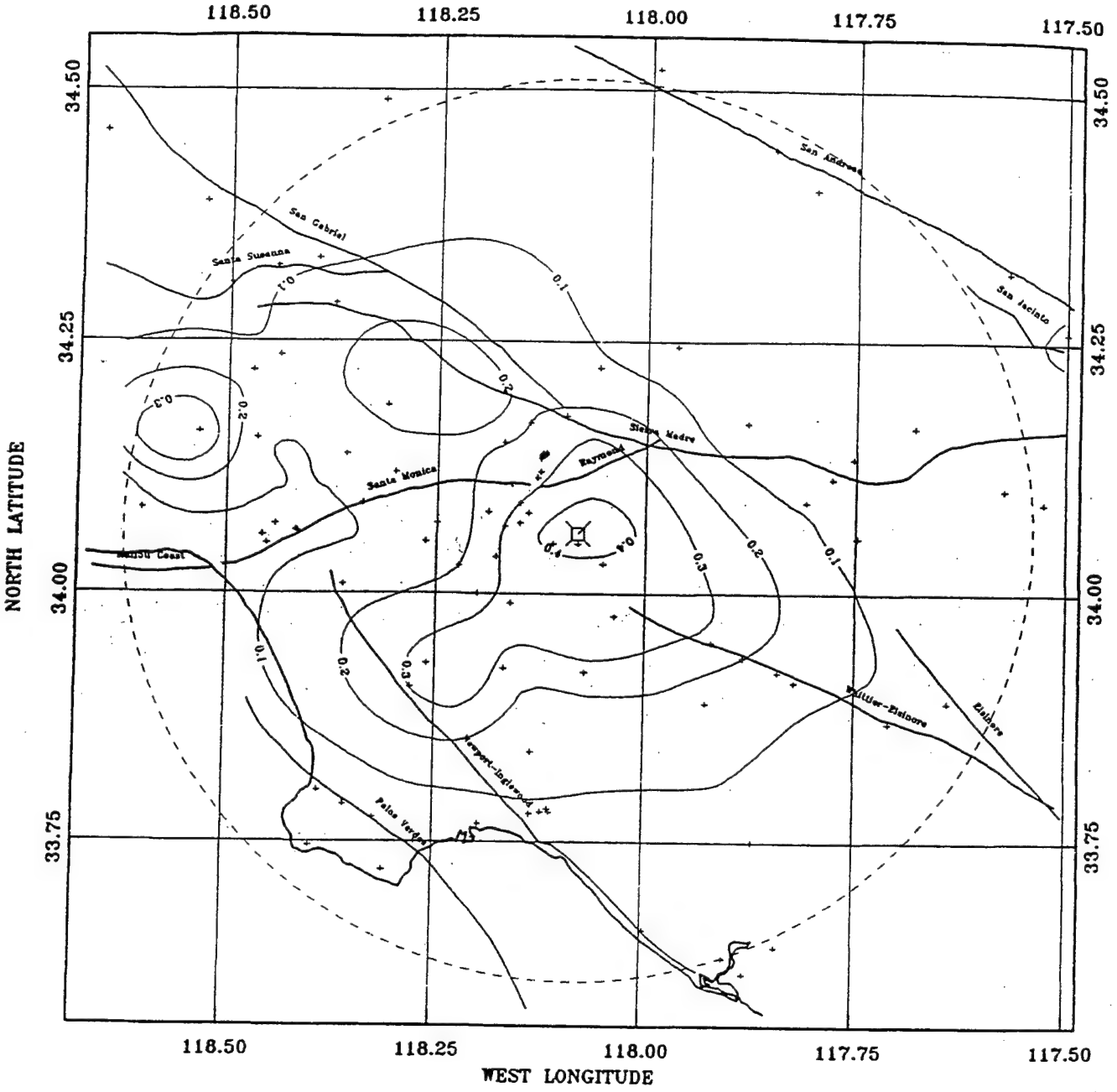
Stations – total: 348, with data: 343, without: 4, rejected: 1, in plot: 199

Map File: CALINE2.DAT
Command File: NR50HWT.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: NRDGDIS.PRN
(Lambert conformal projection)
1995 MAY 28 16:13:55.57

Fig. NRDG-50-MAX w/o TAR



Whittier Earthquake M=5.9 of October 1, 1987

Maximum North-South Acceleration

RADIUS OF CIRCLE IS 50 KM

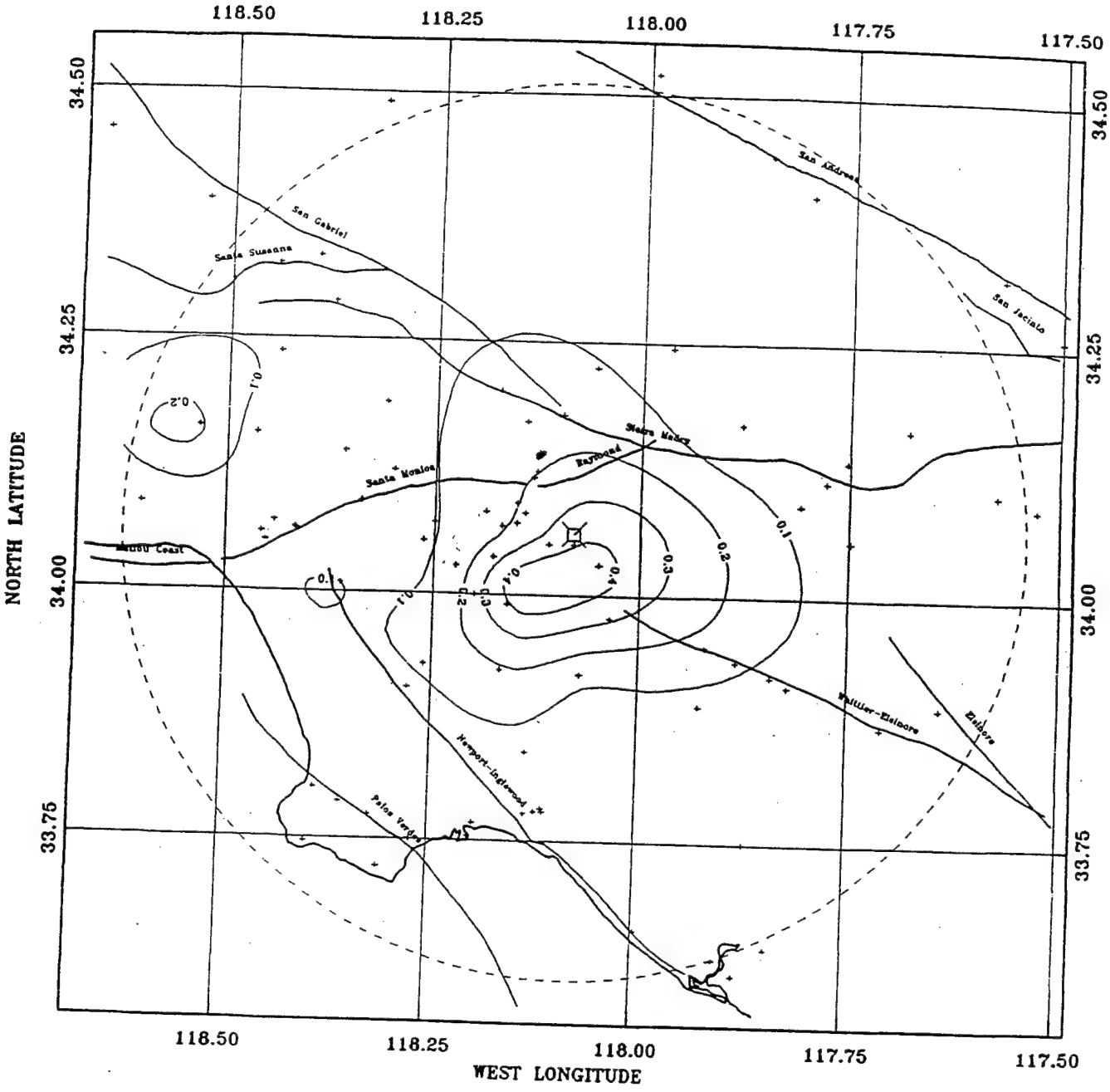
Stations – total: 184, with data: 184, without: 0, rejected: 0, in plot: 116

Map File: CALINE2.DAT
Command File: WH50NC.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: WHITDIS.PRN
(Lambert conformal projection)
1995 MAY 22 13:07:59.48

Fig. WHIT-50-NS (Col. M)



Whittier Earthquake M=5.9 of October 1, 1987

Maximum Vertical Acceleration

RADIUS OF CIRCLE IS 50 KM

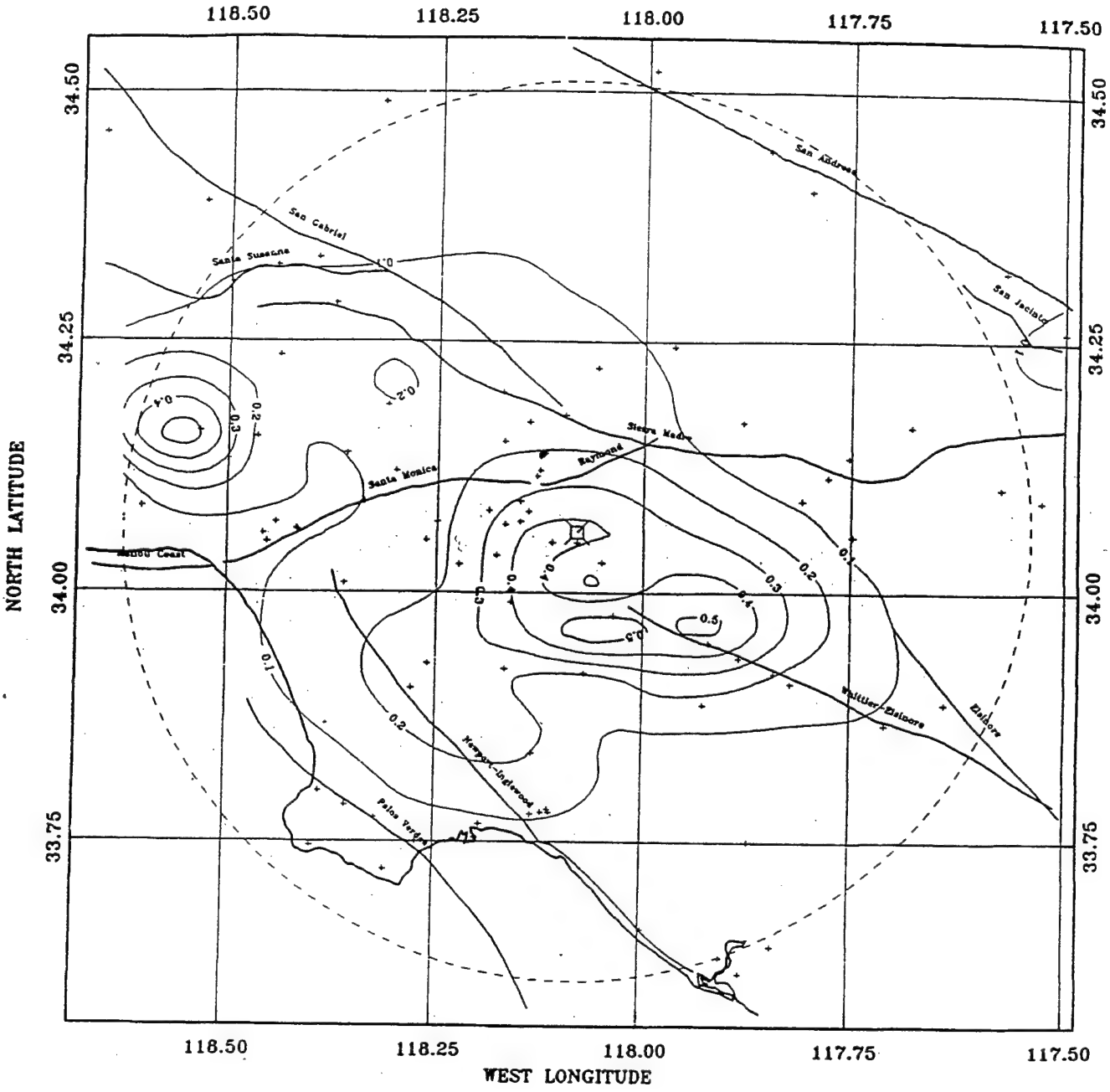
Stations – total: 184, with data: 181, without: 3, rejected: 0, in plot: 114

Map File: CALINE2.DAT
Command File: WH50VC.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: WHITDIS.PRN
(Lambert conformal projection)
1995 MAY 22 13:08:56.21

Fig. WHIT-50-V (Col. N)



Whittier Earthquake M=5.9 of October 1, 1987

Maximum East-West Acceleration

RADIUS OF CIRCLE IS 50 KM

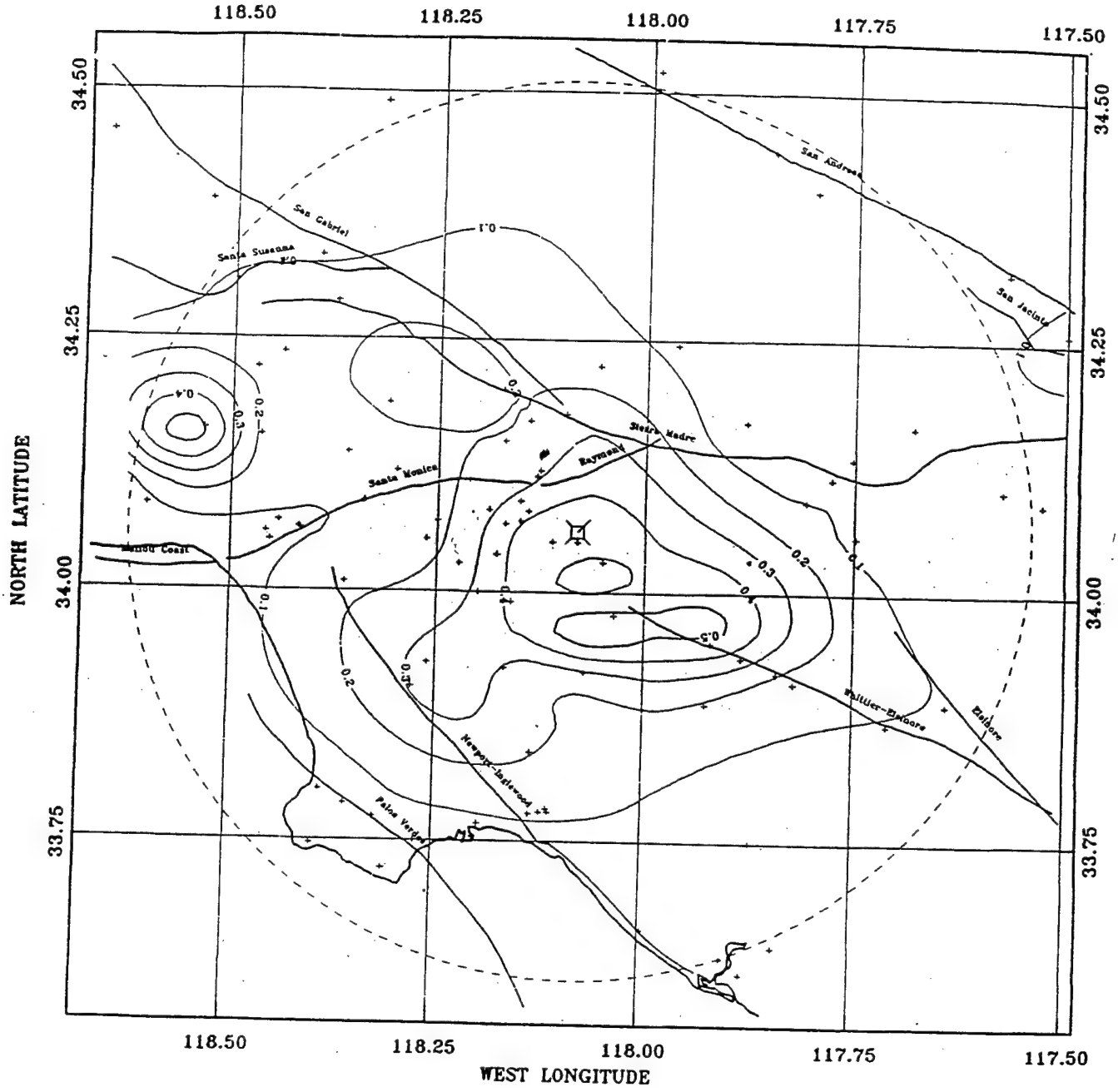
Stations – total: 184, with data: 183, without: 1, rejected: 0, in plot: 115

Map File: CALINE2.DAT
Command File: WH50EC.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: WHITDIS.PRN
(Lambert conformal projection)
1995 MAY 22 13:09:57.02

Fig. WHIT-50-EW (Col. 0)



Whittier Earthquake M=5.9 of October 1, 1987

Maximum Horizontal Acceleration

RADIUS OF CIRCLE IS 50 KM

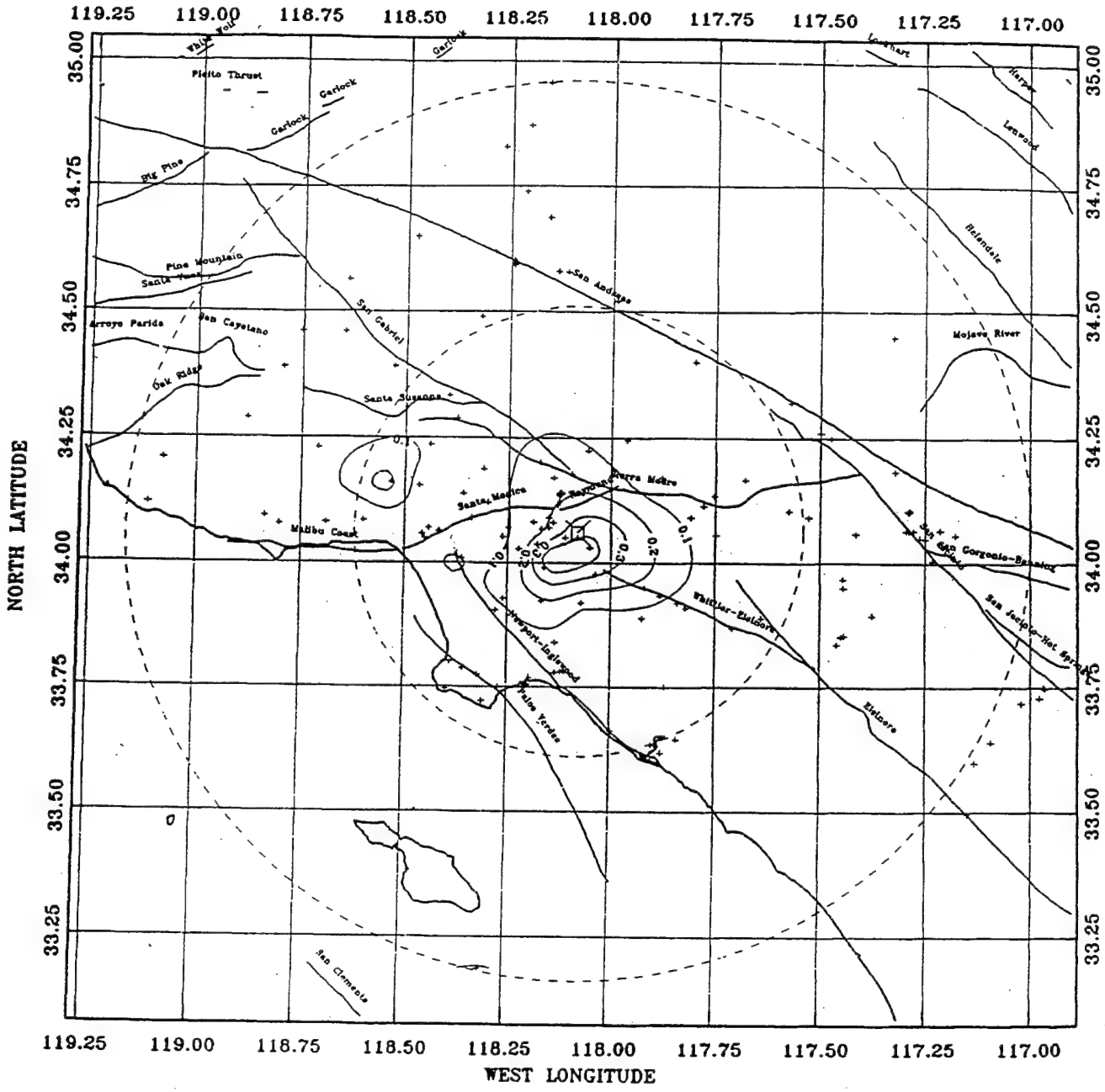
Stations – total: 184, with data: 184, without: 0, rejected: 0, in plot: 116

Map File: CALINE2.DAT
Command File: WH50HC.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: WHITDIS.PRN
(Lambert conformal projection)
1995 MAY 22 13:10:48.26

Fig. WHIT-50-MAX (Col. P)



Whittier Earthquake M=5.9 of October 1, 1987

Maximum Vertical Acceleration

RADIUS OF LARGEST CIRCLE IS 100 KM

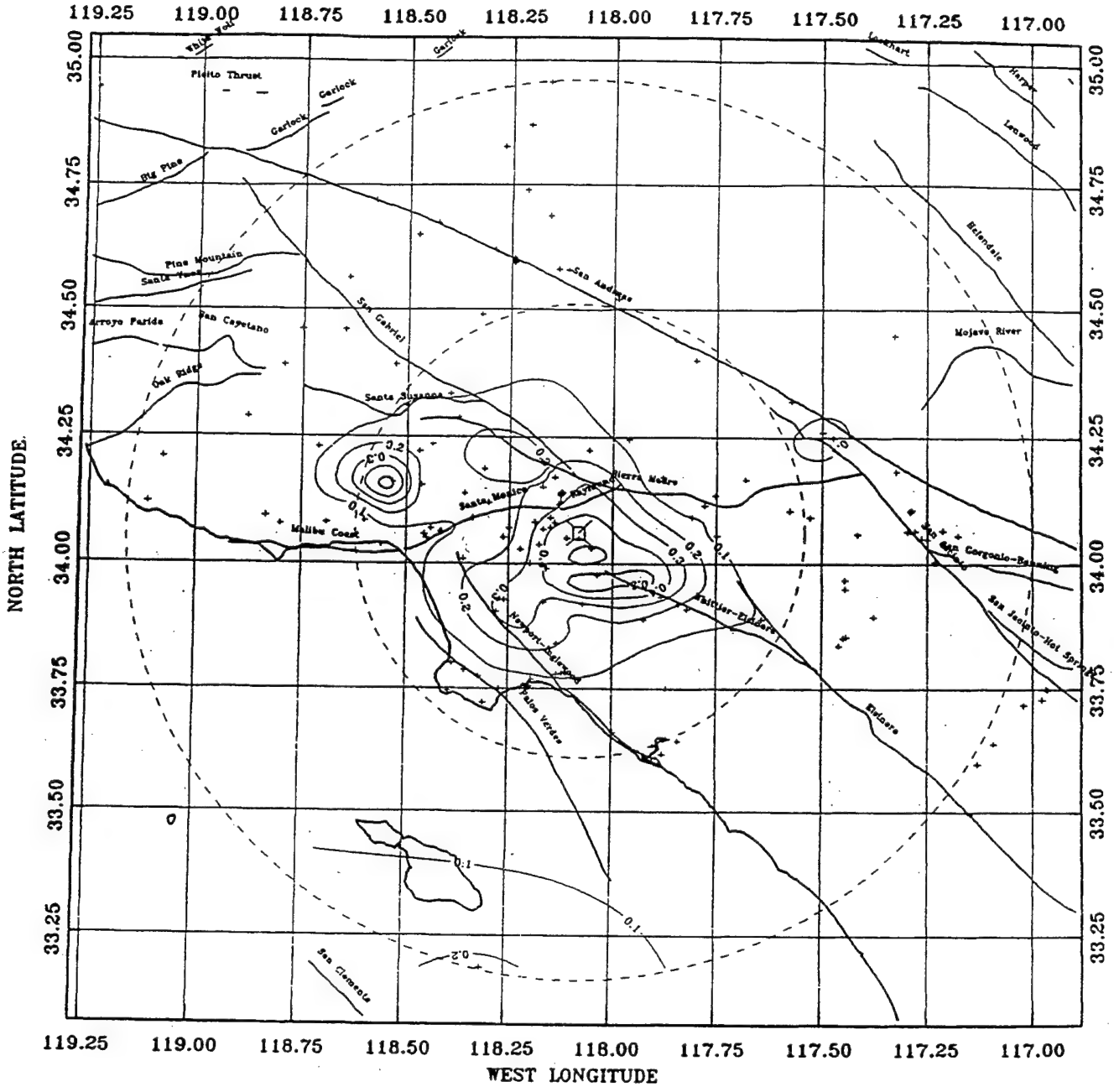
Stations – total: 184, with data: 181, without: 3, rejected: 0, in plot: 178

Map File: CALINE2.DAT
Command File: WH100VC.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: WHITDIS.PRN
(Lambert conformal projection)
1995 MAY 22 13:13:36.61

Fig. WHIT-100-V (Col. N)



Whittier Earthquake M=5.9 of October 1, 1987

Maximum Horizontal Acceleration

RADIUS OF LARGEST CIRCLE IS 100 KM

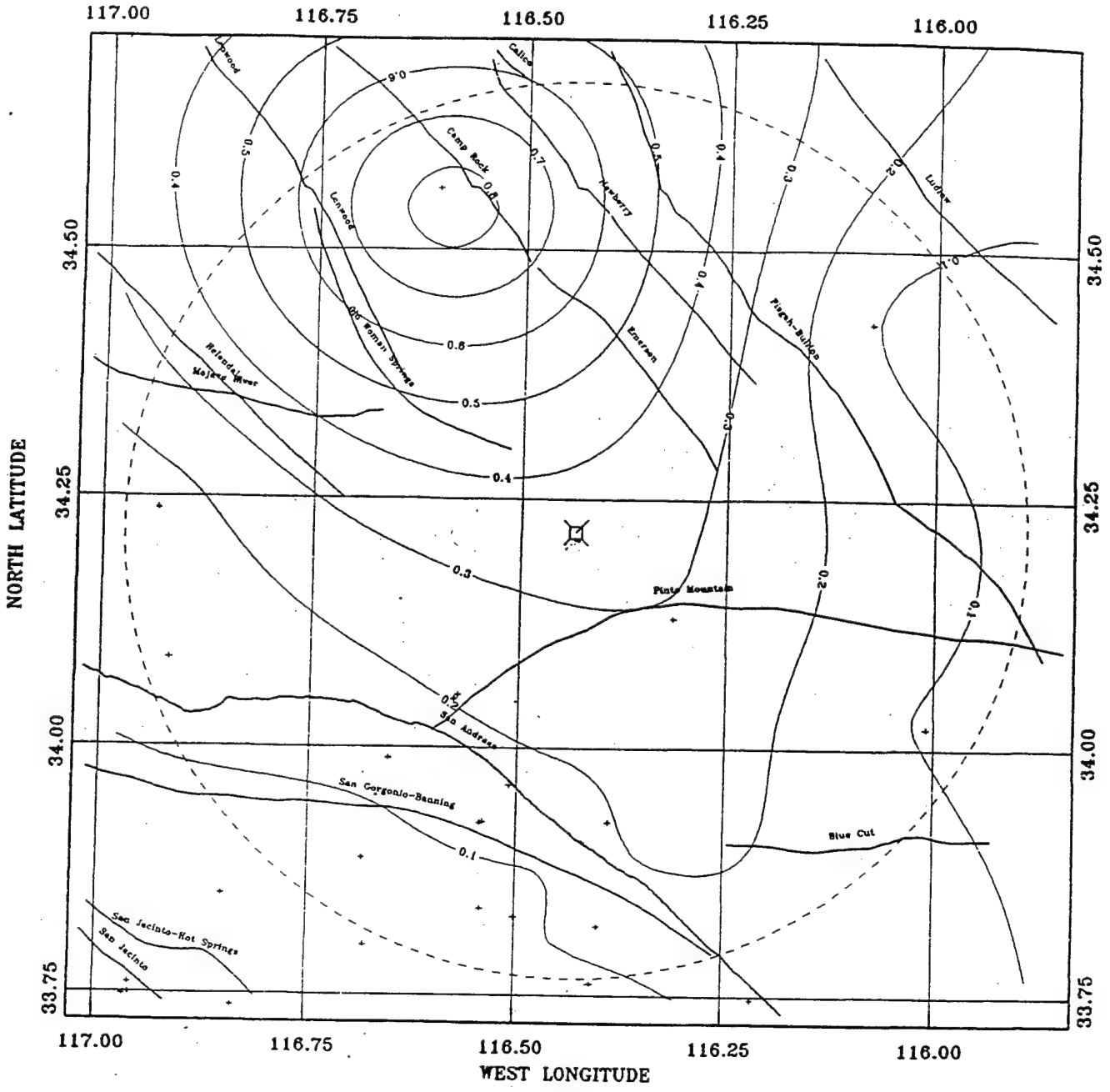
Stations – total: 184, with data: 184, without: 0, rejected: 0, in plot: 181

Map File: CALINE2.DAT
Command File: WH100HC.CAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: WHITDIS.PRN
(Lambert conformal projection)
1995 MAY 22 13:16:26.44

Fig. WHIT-100-MAX (Col. P)



Landers Earthquake M=7.5 of June 28, 1992

Maximum North-South Acceleration

RADIUS OF CIRCLE IS 50 KM

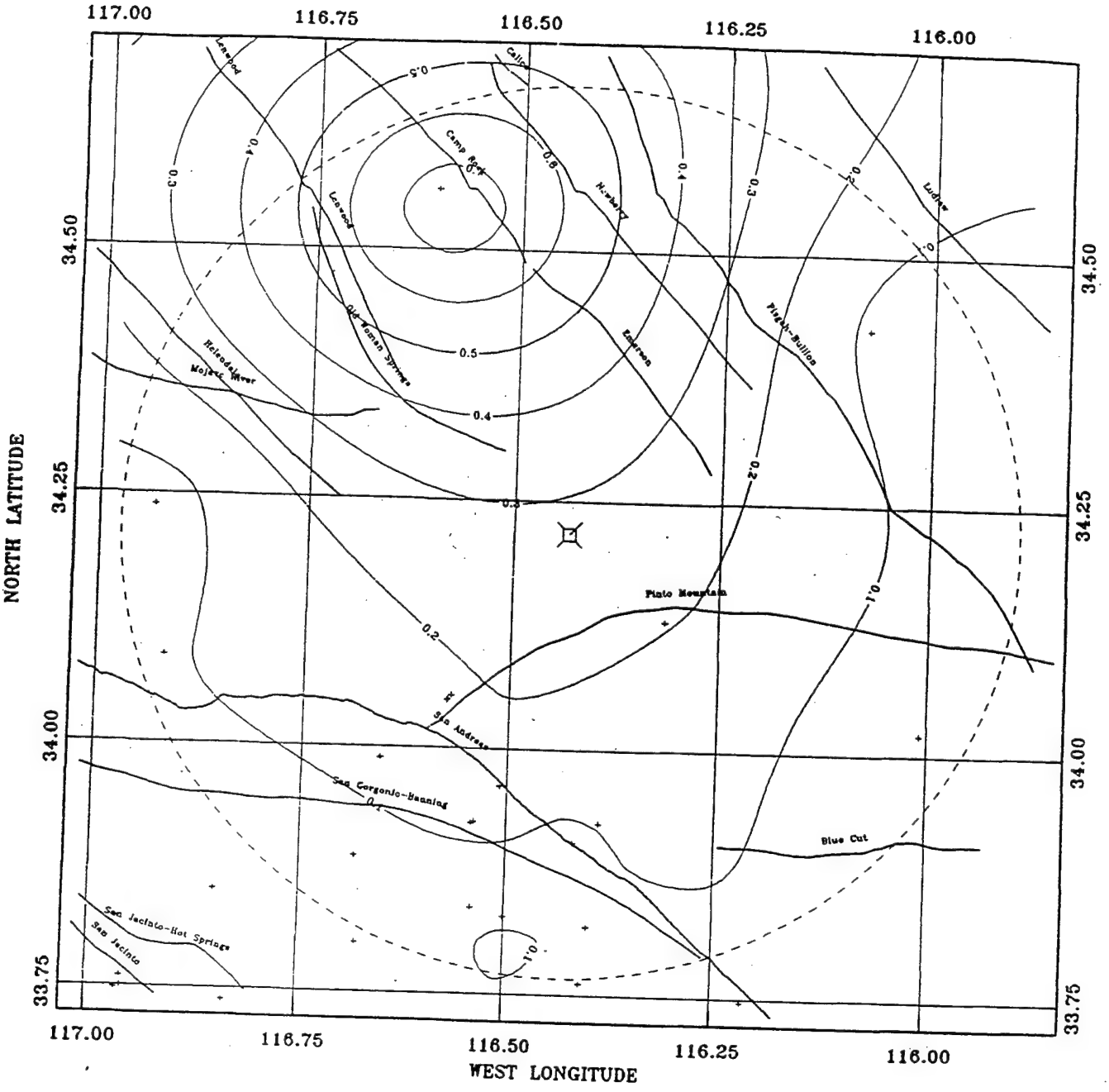
Stations – total: 162, with data: 162, without: 0, rejected: 0, in plot: 28

Map File: CALINE2.DAT
Command File: LN50NC.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: LANDDIS.PRN
(Lambert conformal projection)
1995 MAY 22 04:37:27.86

Fig. LAND-50-NS (Col. M)



Landers Earthquake M=7.5 of June 28, 1992

Maximum Vertical Acceleration

RADIUS OF CIRCLE IS 50 KM

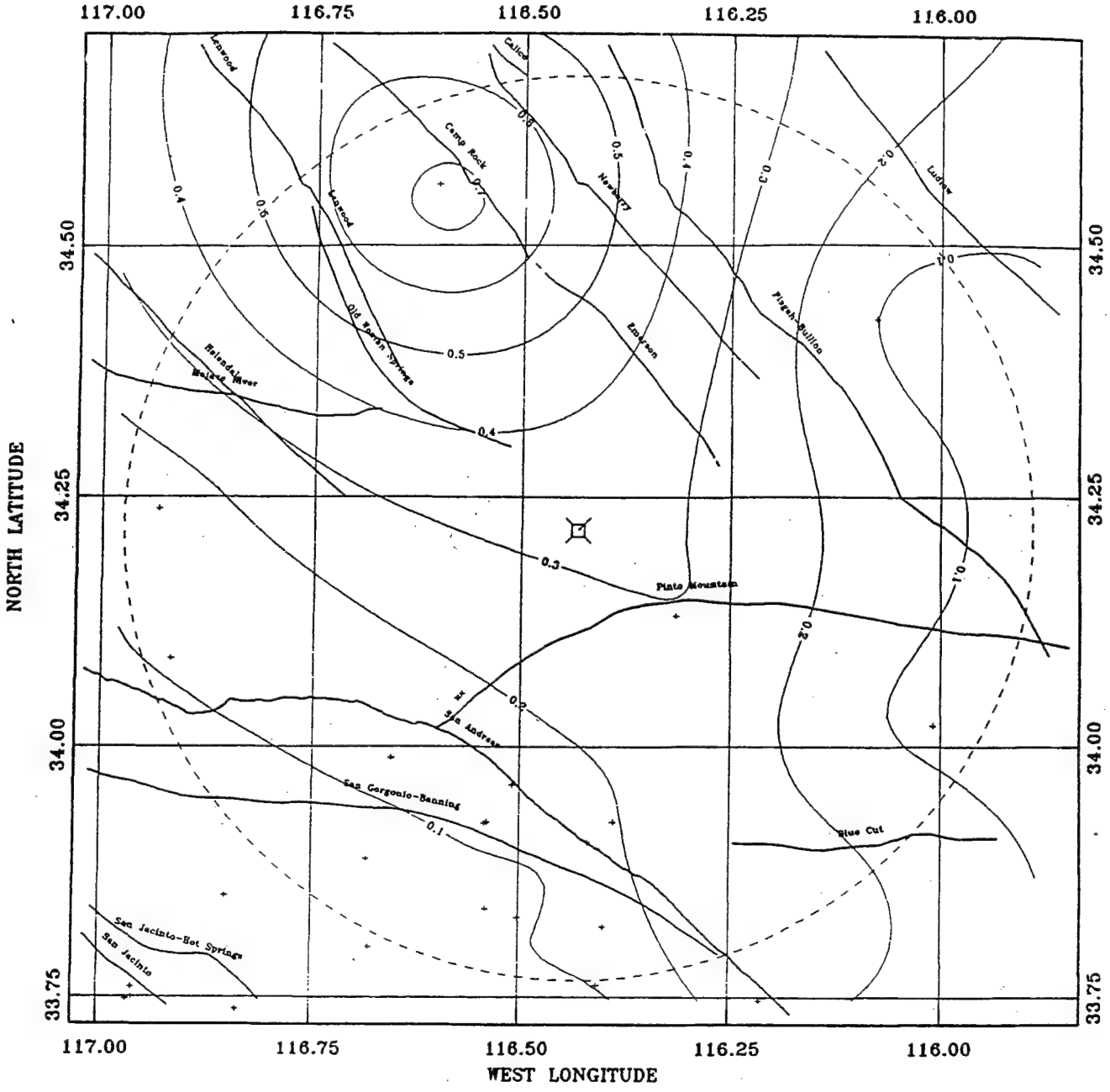
Stations – total: 162, with data: 161, without: 1, rejected: 0, in plot: 28

Map File: CALINE2.DAT
Command File: LN50VC.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: LANDDIS.PRN
(Lambert conformal projection)
1995 MAY 22 04:50:17.86

Fig. LAND-50-V (Col. N)



Landers Earthquake M=7.5 of June 28, 1992

Maximum East-West Acceleration

RADIUS OF CIRCLE IS 50 KM

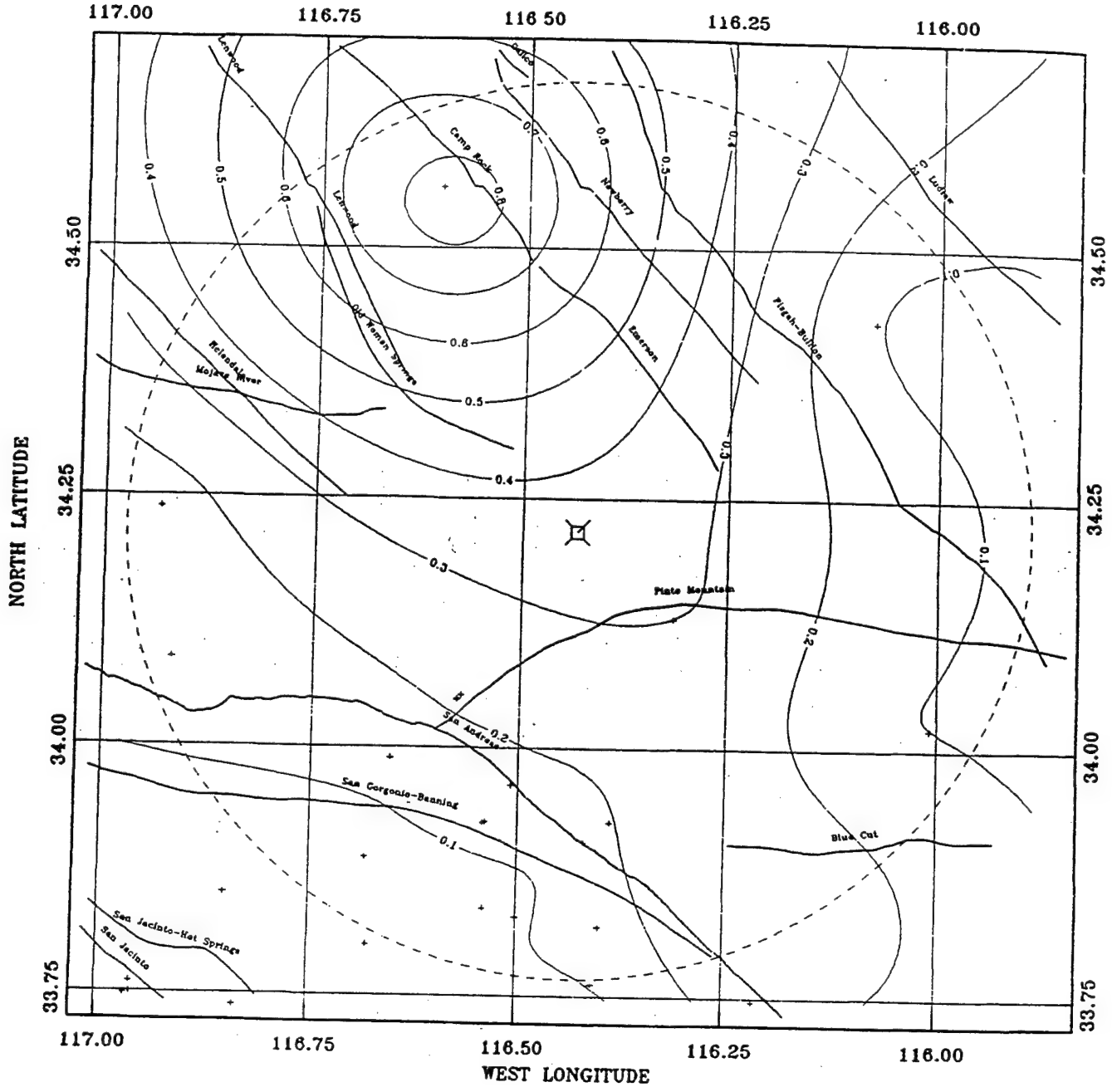
Stations - total: 162, with data: 161, without: 1, rejected: 0, in plot: 28

Map File: CALINE2.DAT
Command File: LN50EC.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: LANDDIS.PRN
(Lambert conformal projection)
1995 MAY 22 04:51:11.68

Fig. LAND-50-EW (Col. 0)



Landers Earthquake M=7.5 of June 28, 1992

Maximum Horizontal Acceleration

RADIUS OF CIRCLE IS 50 KM

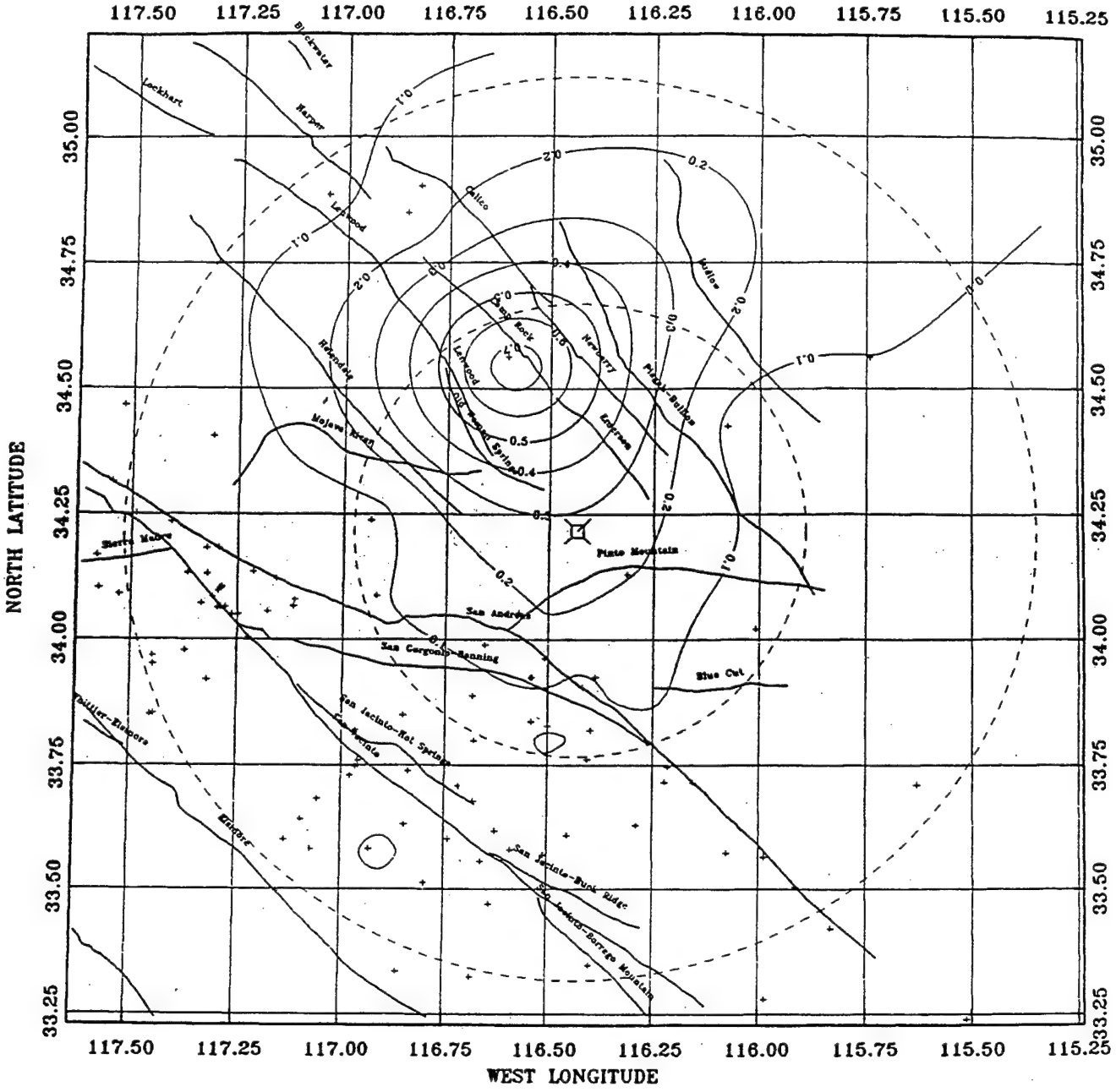
Stations – total: 162, with data: 162, without: 0, rejected: 0, in plot: 28

Map File: CALINE2.DAT
Command File: LN50HC.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: LANDDIS.PRN
(Lambert conformal projection)
1995 MAY 22 04:52:11.55

Fig. LAND-50-MAX (Col. P)



Landers Earthquake M=7.5 of June 28, 1992

Maximum Vertical Acceleration

RADIUS OF LARGEST CIRCLE IS 100 KM

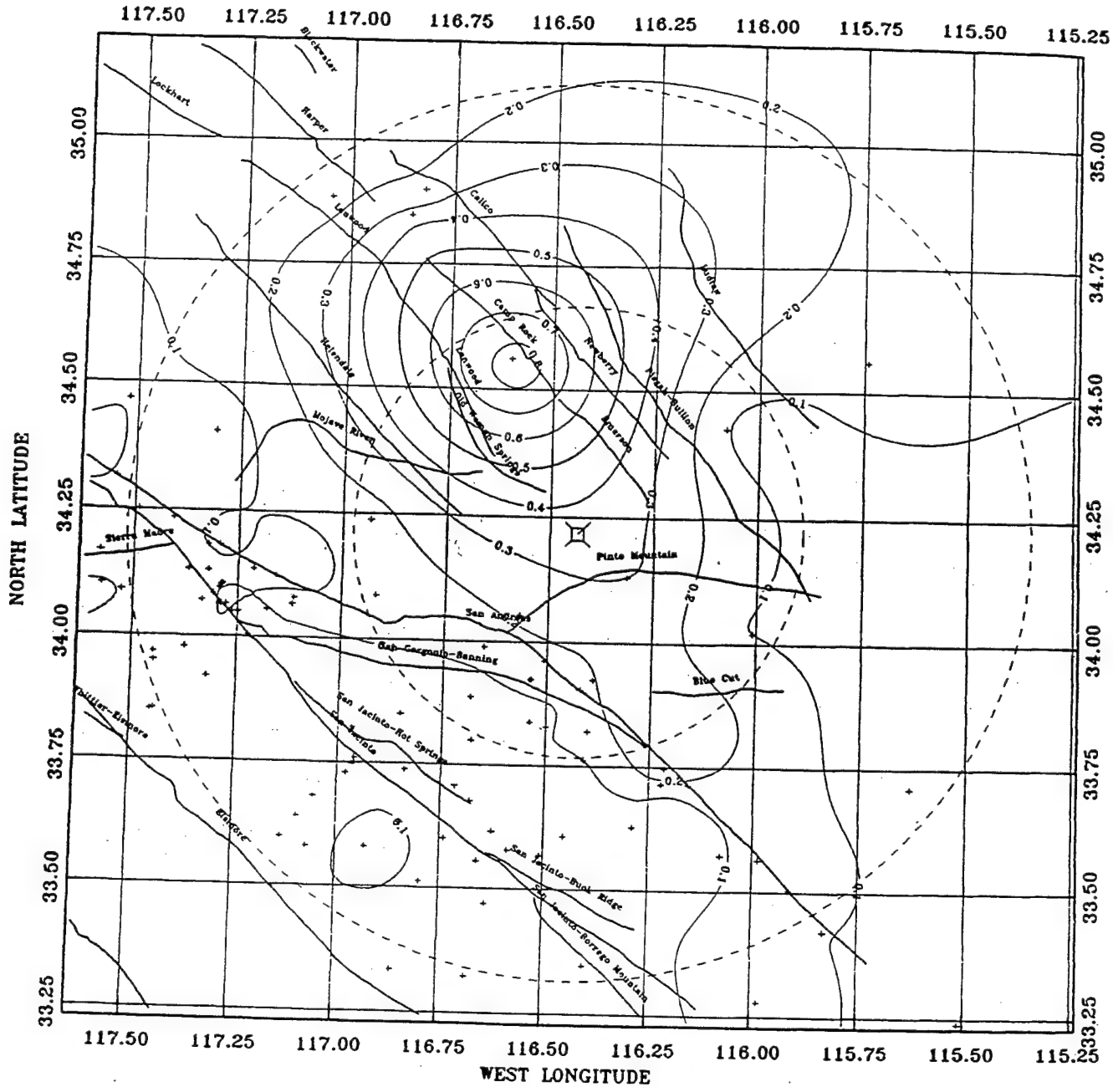
Stations – total: 162, with data: 161, without: 1, rejected: 0, in plot: 107

Map File: CALINE2.DAT
Command File: LN100VC.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: LANDDIS.PRN
(Lambert conformal projection)
1995 MAY 22 04:40:26.80

Fig. LAND-100-V (Col. N)



Landers Earthquake M=7.5 of June 28, 1992

Maximum Horizontal Acceleration

RADIUS OF LARGEST CIRCLE IS 100 KM

Stations – total: 162, with data: 162, without: 0, rejected: 0, in plot: 108

Map File: CALINE2.DAT
Command File: LN100HC.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: LANDDIS.PRN
(Lambert conformal projection)
1995 MAY 22 04:43:42.28

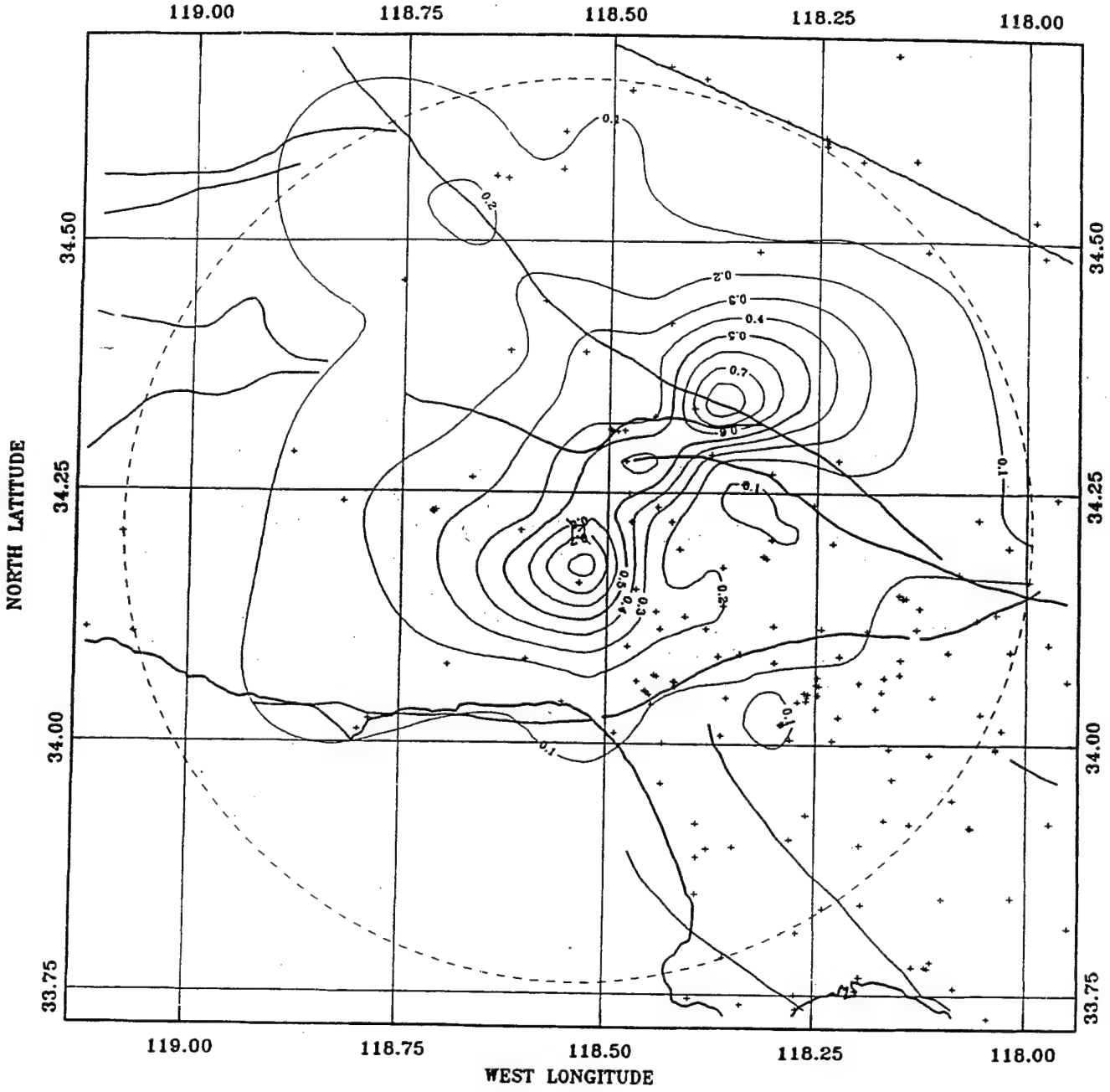
Fig. LAND-100-MAX (Col. P)

Group 3. Ground Motion Adjusted for Site and Structure

Fig. NRDG-Adj-50-V (Col. V)

Fig. WHIT-Adj-50-V (Col. V)
Fig. WHIT-Adj-50-MAX (Col. X)

Fig. LAND-Adj-50-V (Col. V)
Fig. LAND-Adj-50-MAX (Col. X)



Northridge Earthquake M=6.6 of January 17, 1994

Vertical Adjusted Acceleration, g

RADIUS OF CIRCLE IS 50 KM

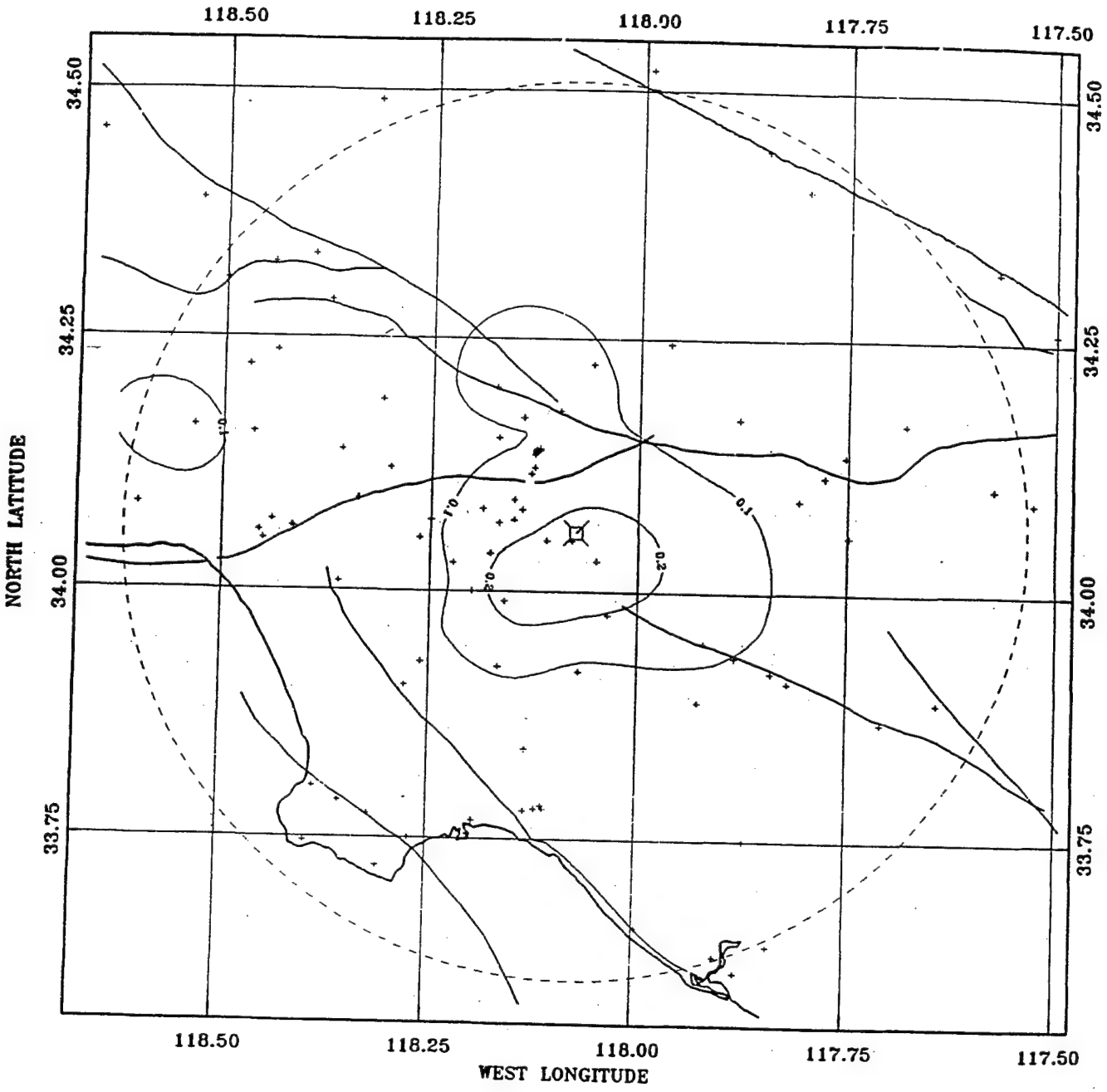
Stations – total: 348, with data: 343, without: 5, rejected: 0, in plot: 198

Map File: CALINE2.DAT
Command File: NR50VA.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: NRDGDIS.PRN
(Lambert conformal projection)
1995 MAY 28 18:14:54.73

Fig. NRDG-Adj-50-V (Col. V)



Whittier Earthquake M=6.1 of October 1, 1987

Vertical Adjusted Acceleration, g

RADIUS OF CIRCLE IS 50 KM

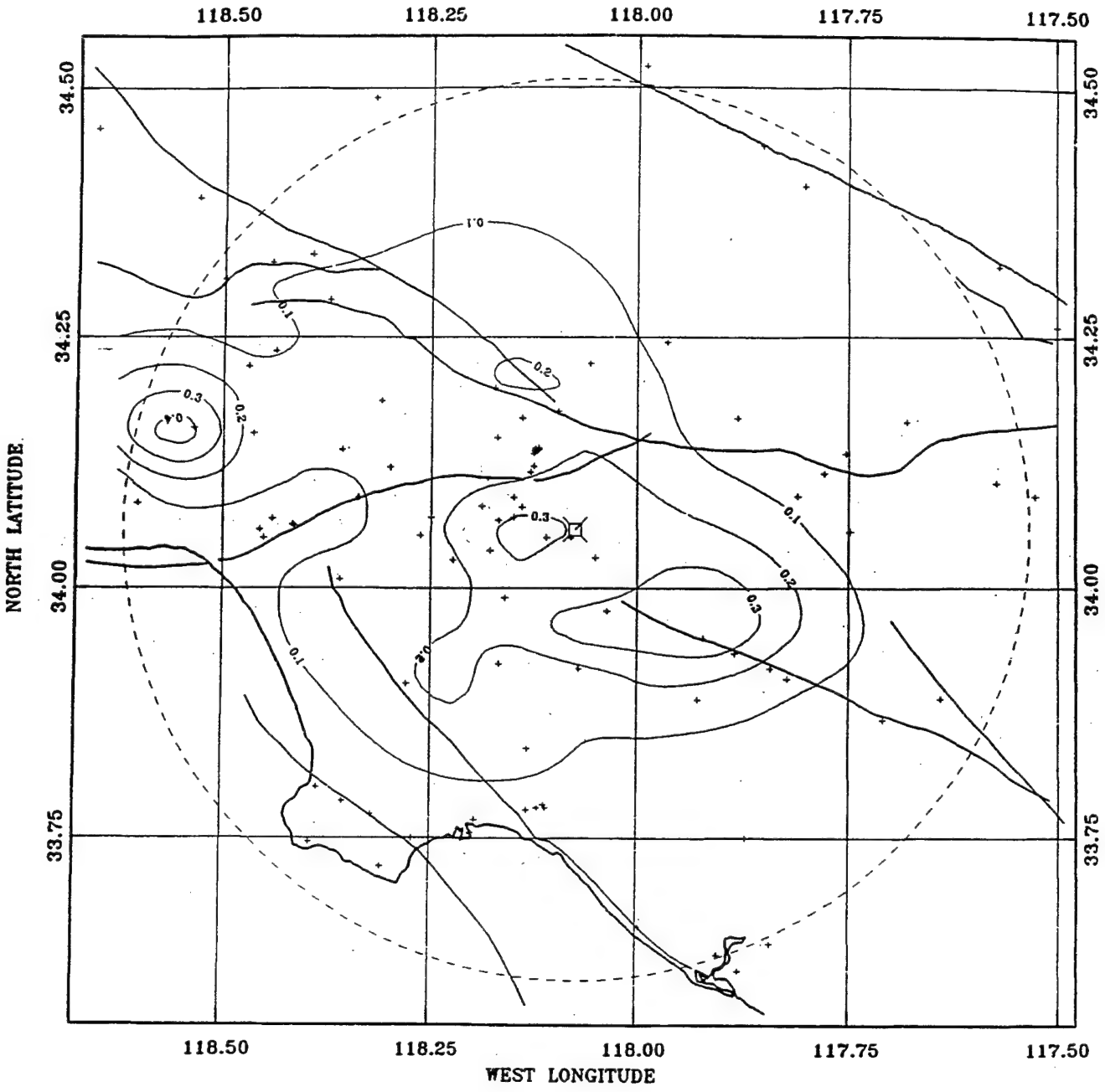
Stations – total: 184, with data: 184, without: 0, rejected: 0, in plot: 116

Map File: CALINE2.DAT
Command File: WH50VA.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: WHITDIS.PRN
(Lambert conformal projection)
1995 MAY 28 18:18:08.34

Fig. WHIT-Adj-50-V (Col. V)



Whittier Earthquake M=6.1 of October 1, 1987

Maximum Adjusted Horizontal Acceleration, g

RADIUS OF CIRCLE IS 50 KM

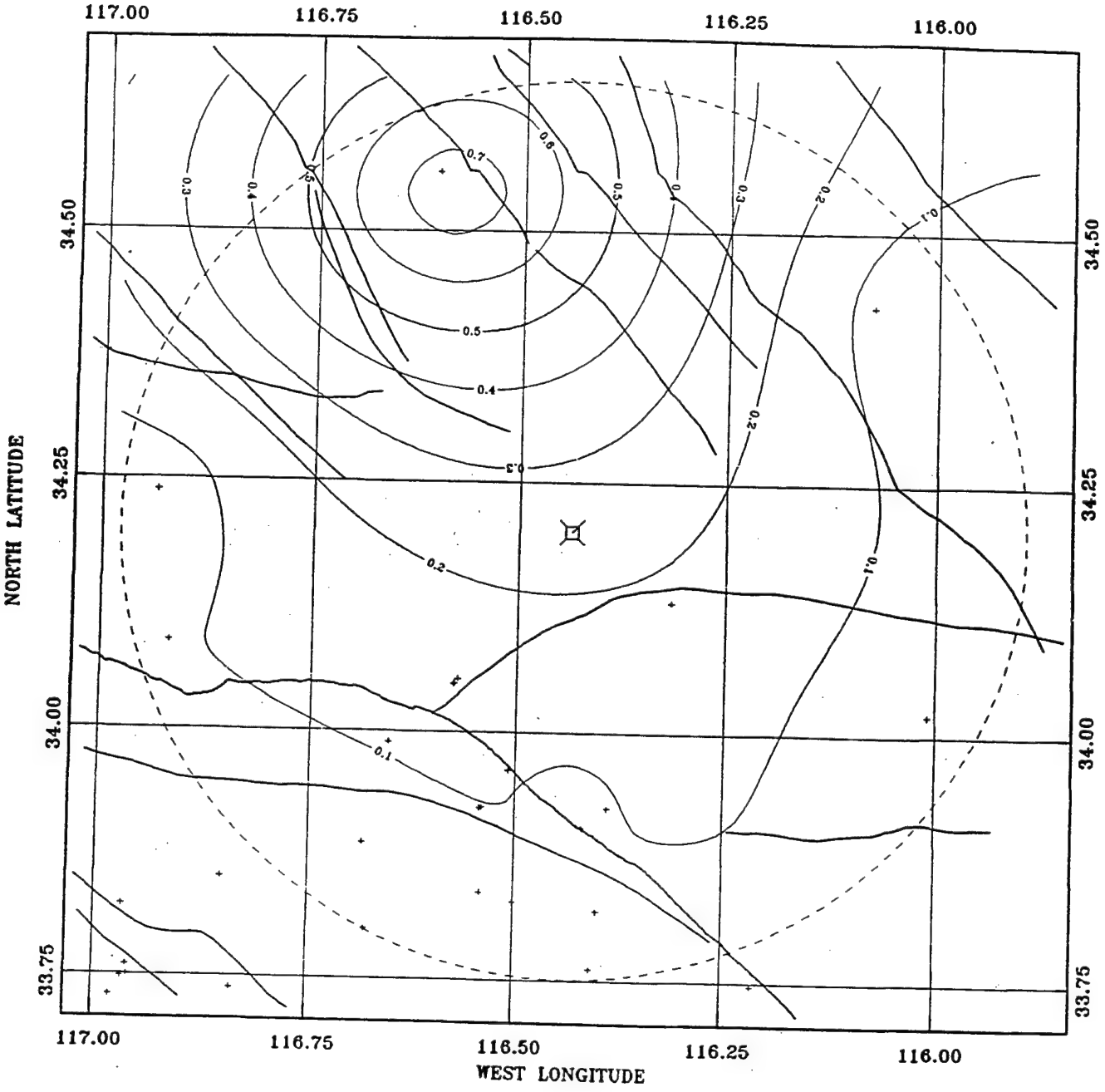
Stations – total: 184, with data: 184, without: 0, rejected: 0, in plot: 116

Map File: CALINE2.DAT
Command File: WH50HA.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: WHITDIS.PRN
(Lambert conformal projection)
1995 MAY 28 16:19:28.75

Fig. WHIT-Adj-50-MAX (Col. X)



Landers Earthquake M=7.5 of June 28, 1992

Vertical Adjusted Acceleration, g

RADIUS OF CIRCLE IS 50 KM

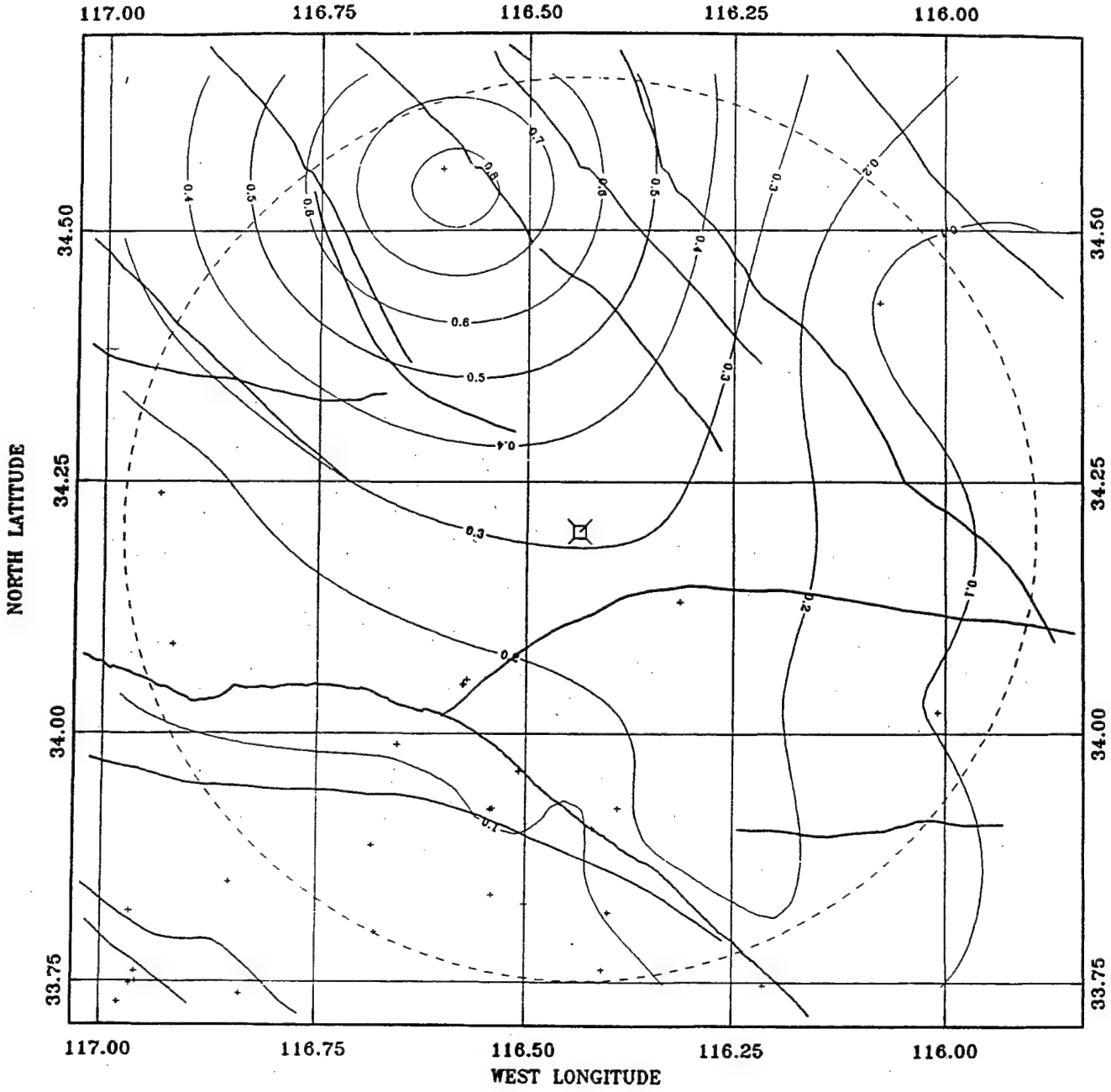
Stations – total: 162, with data: 162, without: 0, rejected: 0, in plot: 29

Map File: CALINE2.DAT
Command File: LN50VA.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: LANDDIS.PRN
(Lambert conformal projection)
1995 MAY 28 18:15:50.09

Fig. LAND-Adj-50-V (Col. V)



Landers Earthquake M=7.5 of June 28, 1992

Maximum Adjusted Horizontal Acceleration, g

RADIUS OF CIRCLE IS 50 KM

Stations – total: 162, with data: 162, without: 0, rejected: 0, in plot: 29

Map File: CALINE2.DAT
Command File: LN50HA.CAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: LANDDIS.PRN
(Lambert conformal projection)
1995 MAY 28 18:16:43.98

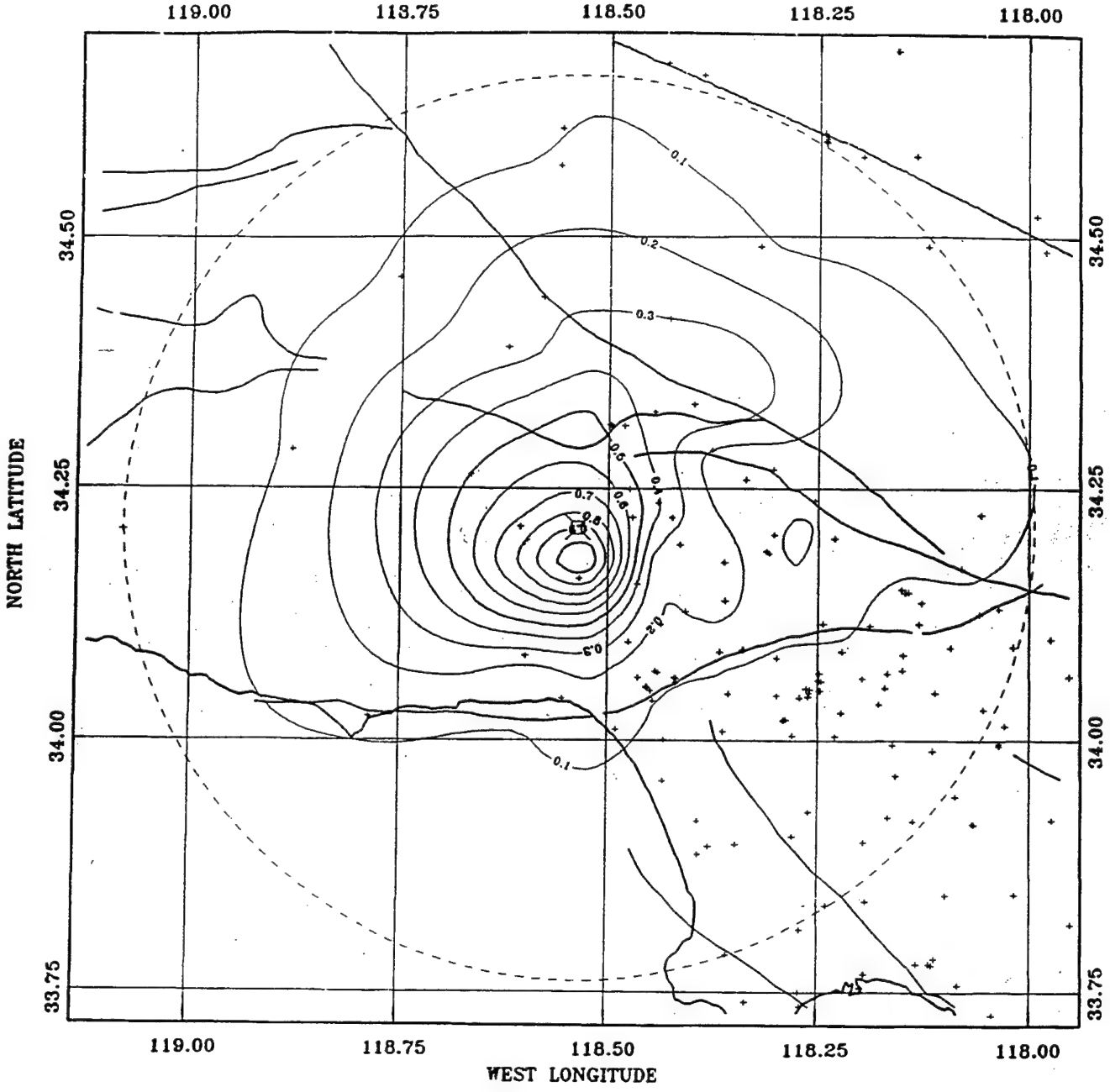
Fig. LAND-Adj-50-MAX (Col. X)

Group 4. Ground Motion with NEHRP Adjustment

Fig. NRDG-NHRP-50-V (Col. AF)
Fig. NRDG-NHRP-50-MAX (Col. AH)

Fig. WHIT-NHRP-50-V (Col. AF)
Fig. WHIT-NHRP-50-MAX (Col. AH)

Fig. LAND-NHRP-50-V (Col. AF)
Fig. LAND-NHRP-50-MAX (Col. AH)



Northridge Earthquake M=6.6 of January 17, 1994

Vertical NEHRP Adjusted Acceleration, g

RADIUS OF CIRCLE IS 50 KM

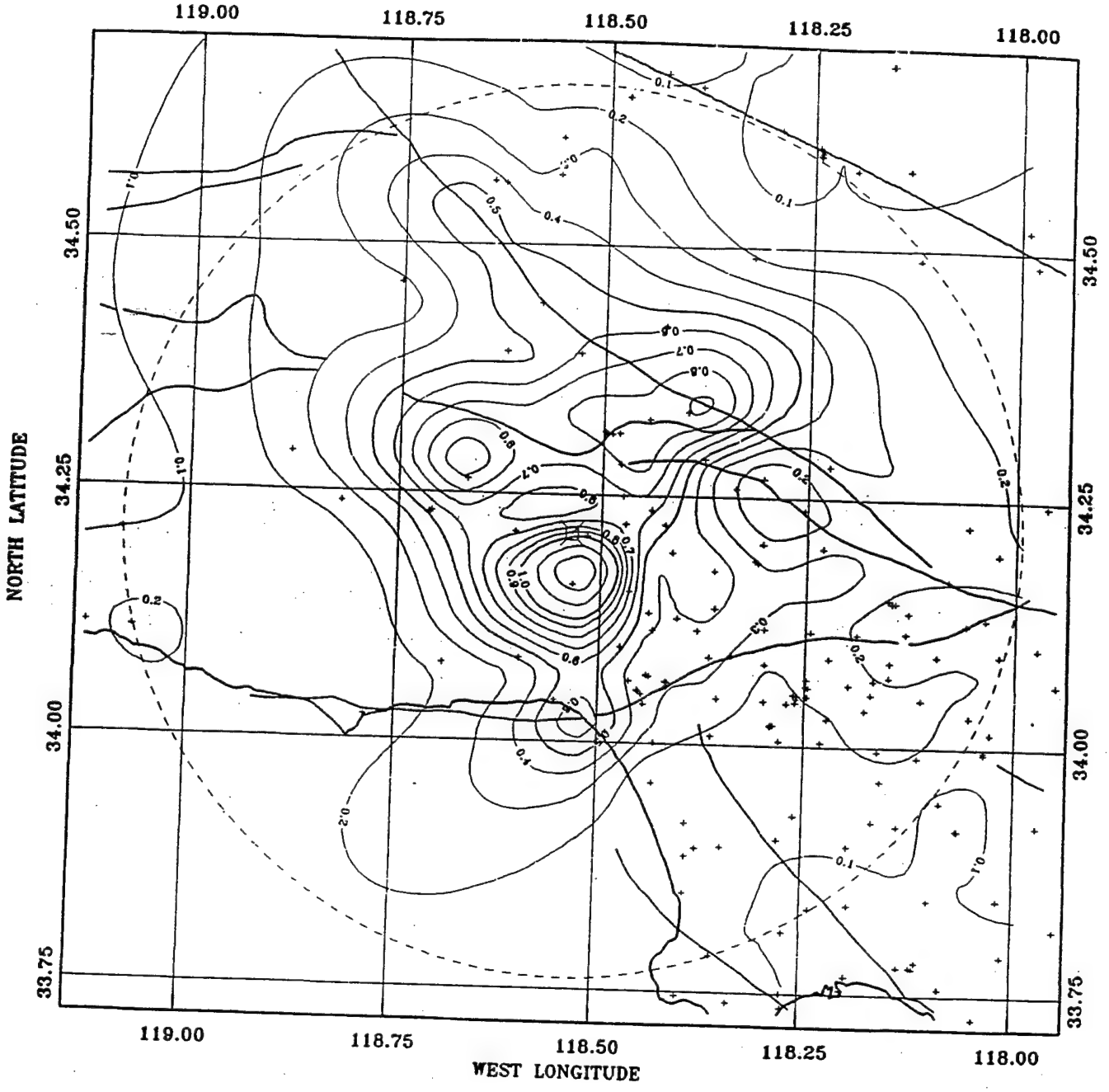
Stations – total: 348, with data: 303, without: 45, rejected: 0, in plot: 171

Map File: CALINE2.DAT
Command File: NR50VN.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: NRDGDIS.PRN
(Lambert conformal projection)
1995 MAY 28 18:20:18.57

Fig. NRDG-NHRP-50-V (Col. AF)



Northridge Earthquake M=6.6 of January 17, 1994

NEHRP Adjusted Maximum Horizontal Acceleration, g

RADIUS OF CIRCLE IS 50 KM

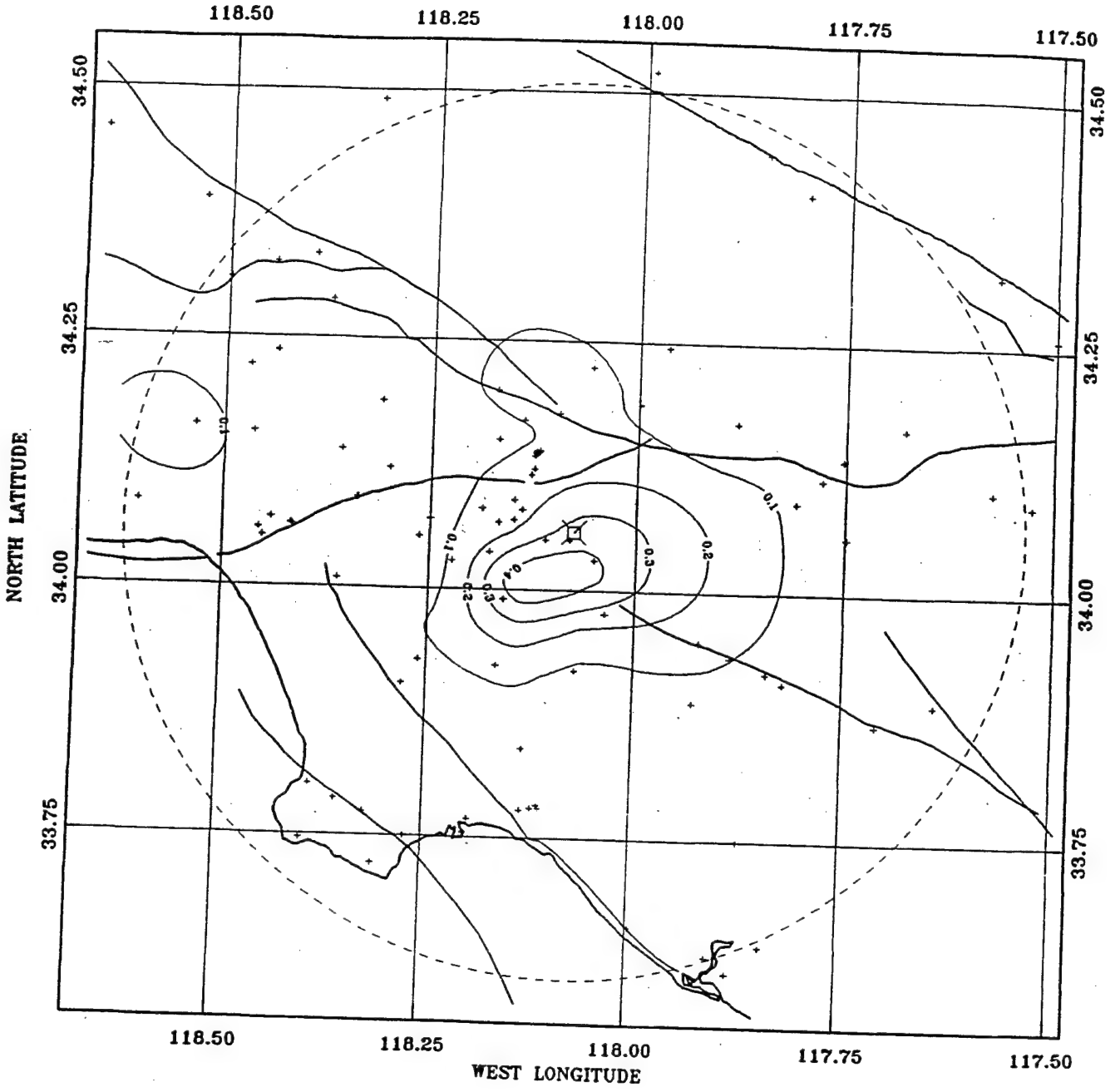
Stations – total: 348, with data: 344, without: 4, rejected: 0, in plot: 200

Map File: CALINE2.DAT
Command File: NR50HN.CAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: NRDGDIS.PRN
(Lambert conformal projection)
1995 MAY 28 18:23:20.43

Fig. NRDG-NHRP-50-MAX (Col. AH)



Whittier Earthquake M=6.1 of October 1, 1987

Vertical NEHRP Adjusted Acceleration, g

RADIUS OF CIRCLE IS 50 KM

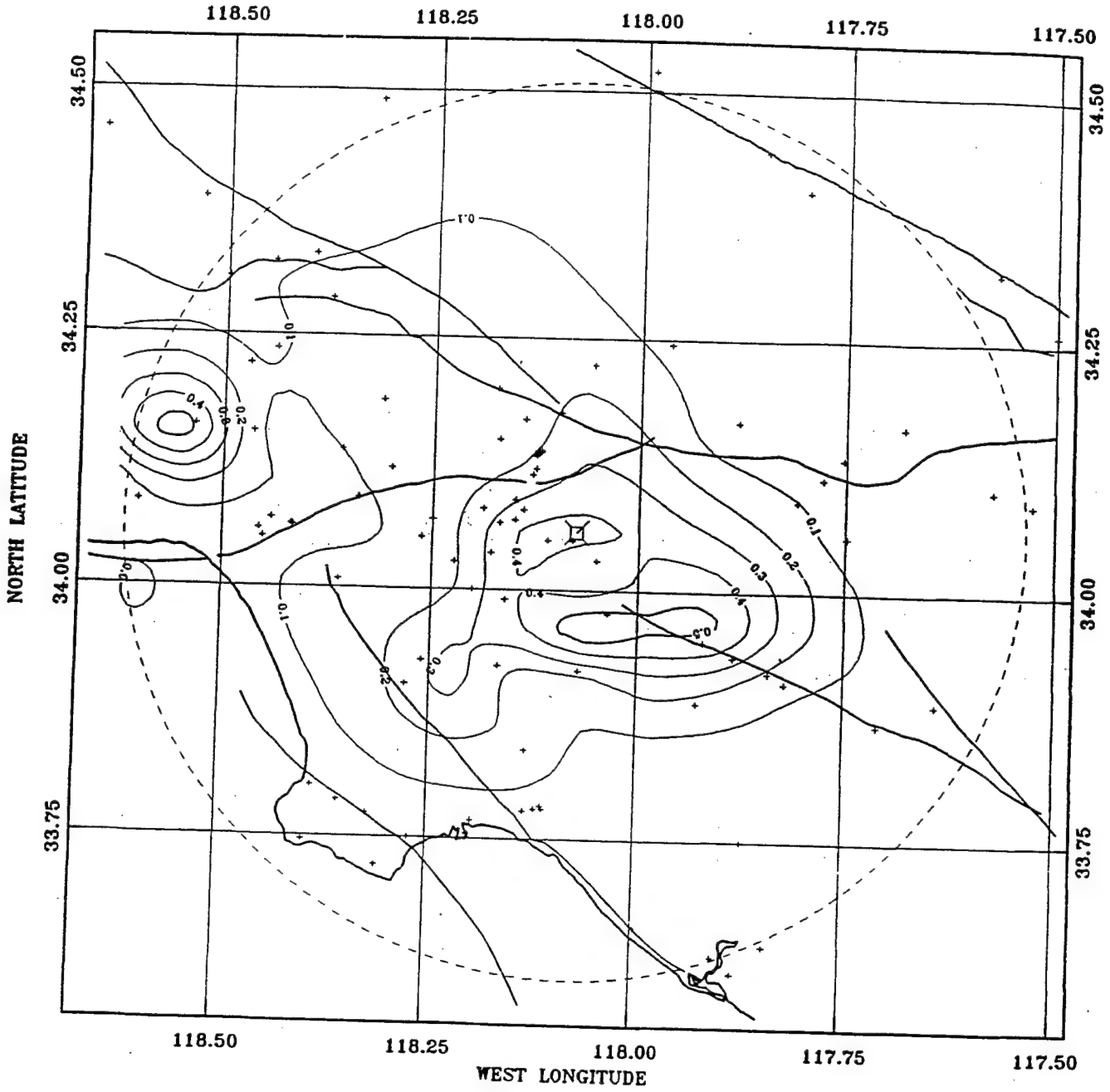
Stations – total: 184, with data: 184, without: 0, rejected: 0, in plot: 116

Map File: CALINE2.DAT
Command File: WH50VN.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: WHITDIS.PRN
(Lambert conformal projection)
1995 MAY 28 18:27:32.15

Fig. WHIT-NHRP-50-V (Col. AF)



Whittier Earthquake M=6.1 of October 1, 1987

NEHRP Adjusted Maximum Horizontal Acceleration, g

RADIUS OF CIRCLE IS 50 KM

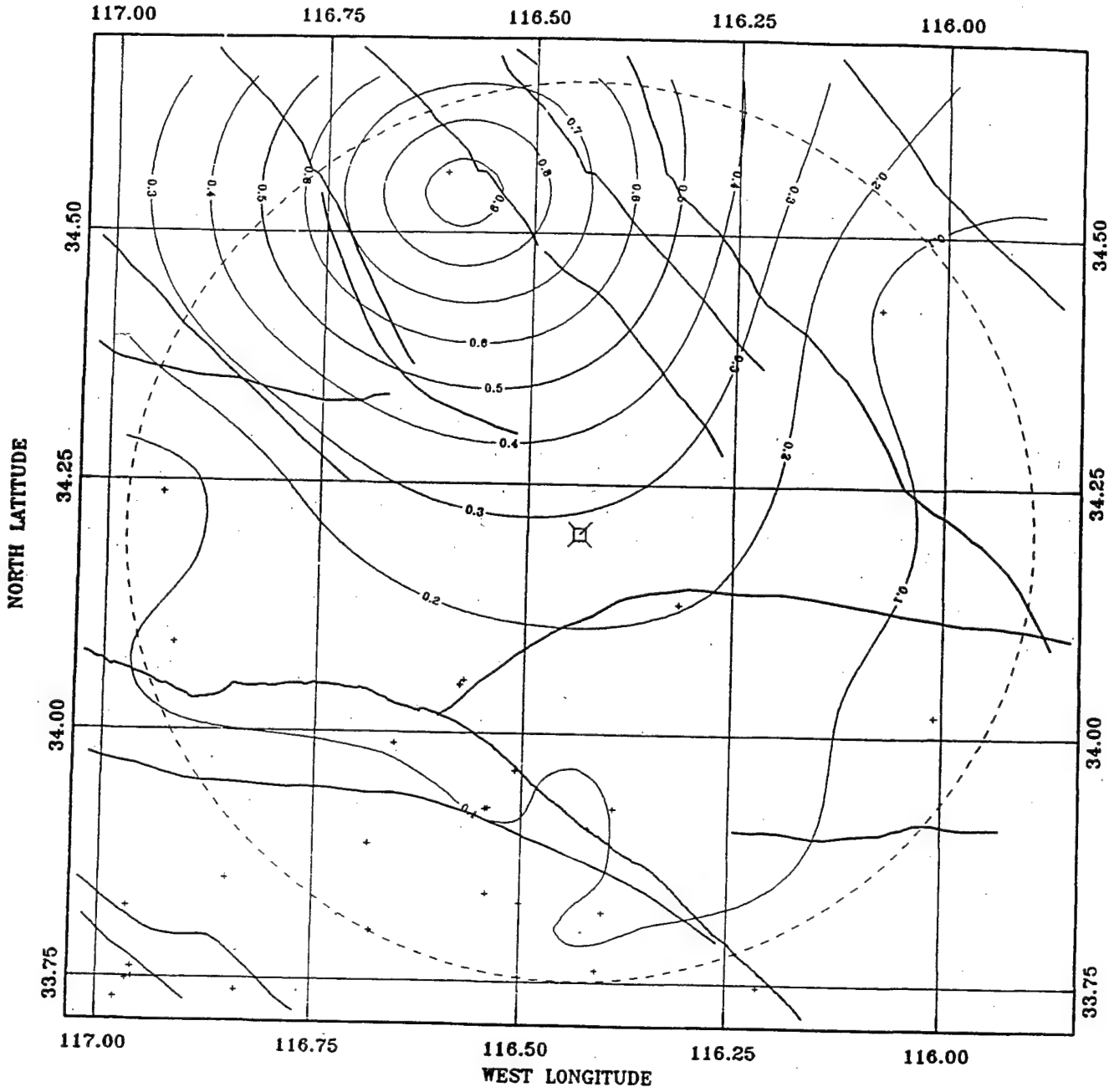
Stations – total: 184, with data: 184, without: 0, rejected: 0, in plot: 116

Map File: CALINE2.DAT
Command File: WH50HN.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: WHITDIS.PRN
(Lambert conformal projection)
1995 MAY 28 18:28:49.98

Fig. WHIT-NHRP-50-MAX (Col. AH)



Landers Earthquake M=7.5 of June 28, 1992

Vertical NEHRP Adjusted Acceleration, g

RADIUS OF CIRCLE IS 50 KM

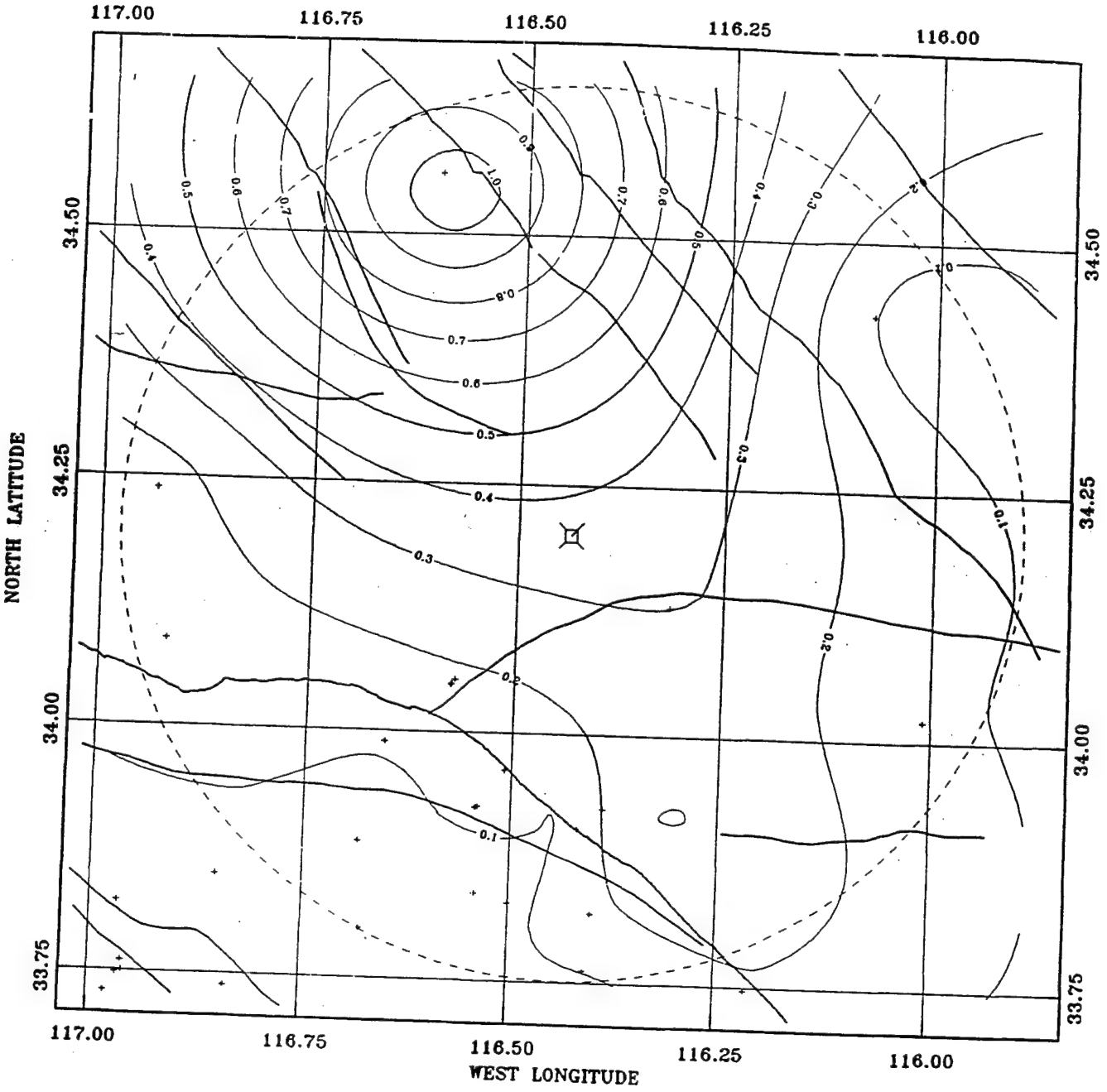
Stations – total: 162, with data: 162, without: 0, rejected: 0, in plot: 29

Map File: CALINE2.DAT
Command File: LN50VN.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: LANDDIS.PRN
(Lambert conformal projection)
1995 MAY 28 16:24:46.72

Fig. LAND-NHRP-50-V (Col. AF)



Landers Earthquake M=7.5 of June 28, 1992

NEHRP Adjusted Maximum Horizontal Acceleration, g

RADIUS OF CIRCLE IS 50 KM

Stations – total: 162, with data: 162, without: 0, rejected: 0, in plot: 29

Map File: CALINE2.DAT
Command File: LN50HN.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: LANDDIS.PRN
(Lambert conformal projection)
1995 MAY 28 18:26:08.17

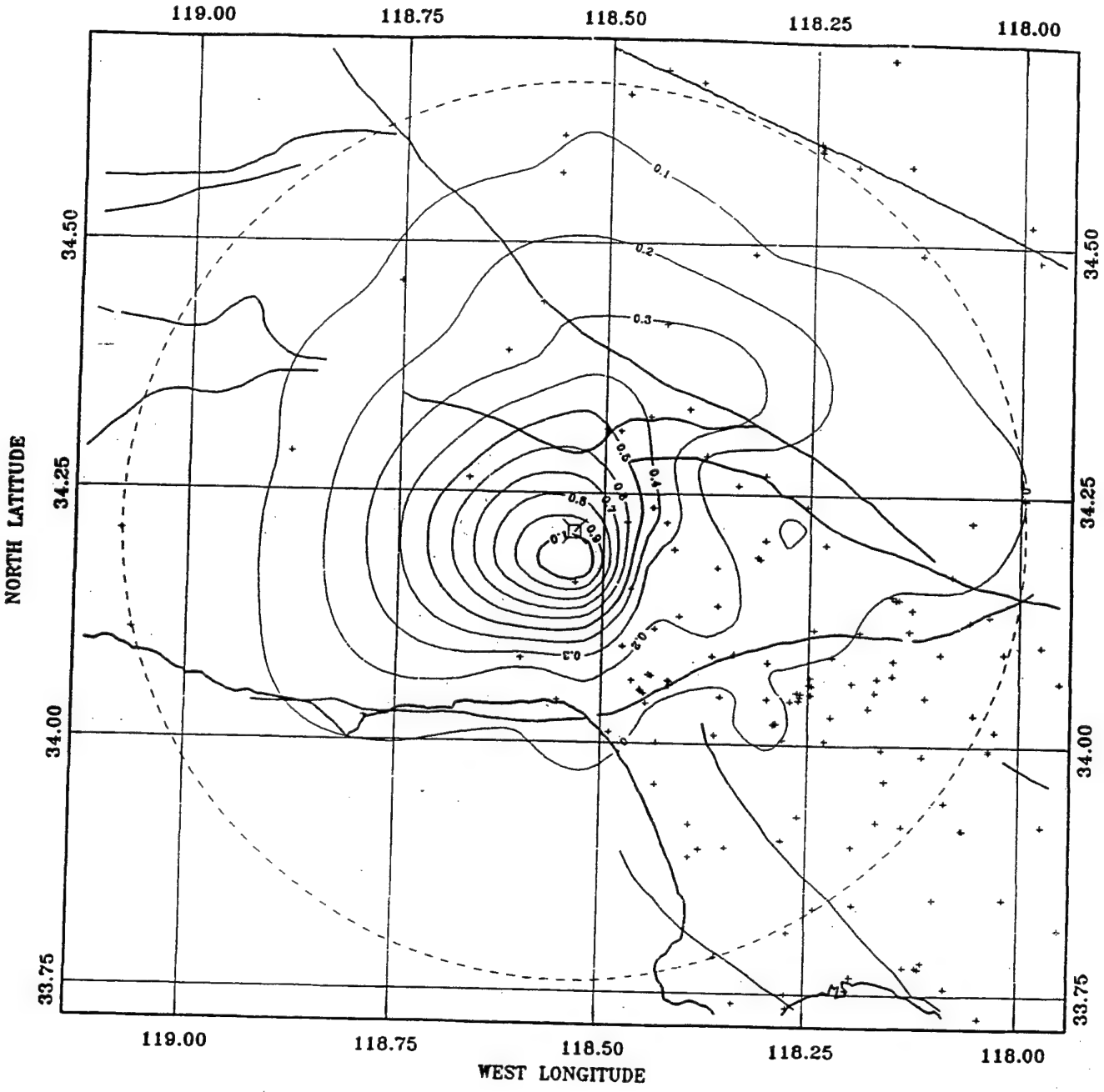
Fig. LAND-NHRP-50-MAX (Col. AH)

Group 5. Ground Motion with NEHRP plus Structural Adjustment

Fig NRDG-NHRP/Str-50-V (Col. AN)
Fig NRDG-NHRP/Str-50-MAX (Col. AP)

Fig. WHIT-NHRP/Str-50-V (Col. AN)
Fig. WHIT-NHRP/Str-50-MAX (Col. AP)

Fig. LAND-NHRP/Str-50-V (Col. AN)
Fig. LAND-NHRP/Str-50-MAX (Col. AP)



Northridge Earthquake M=6.6 of January 17, 1994

Vertical NEHRP+Structure Corrected Acceleration, g

RADIUS OF CIRCLE IS 50 KM

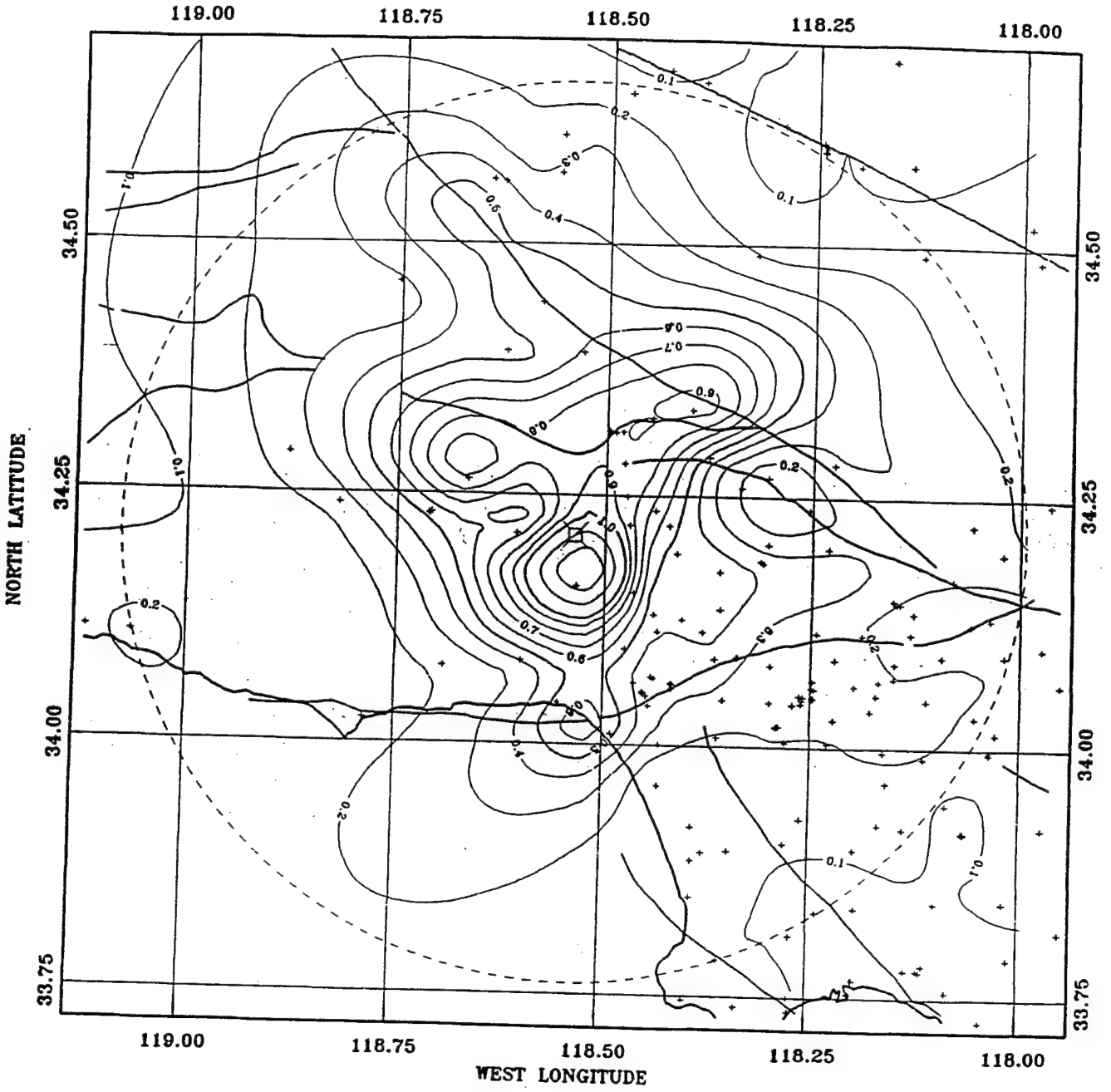
Stations – total: 348, with data: 308, without: 40, rejected: 0, in plot: 173

Map File: CALINE2.DAT
Command File: NR50VS.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: NRDGDIS.PRN
(Lambert conformal projection)
1995 MAY 28 18:31:39.76

Fig. NRDG-NHRP/Str-50-V (Col. AN)



Northridge Earthquake M=6.6 of January 17, 1994

NEHRP+Structure Corrected Maximum Horizontal Acceleration, g

RADIUS OF CIRCLE IS 50 KM

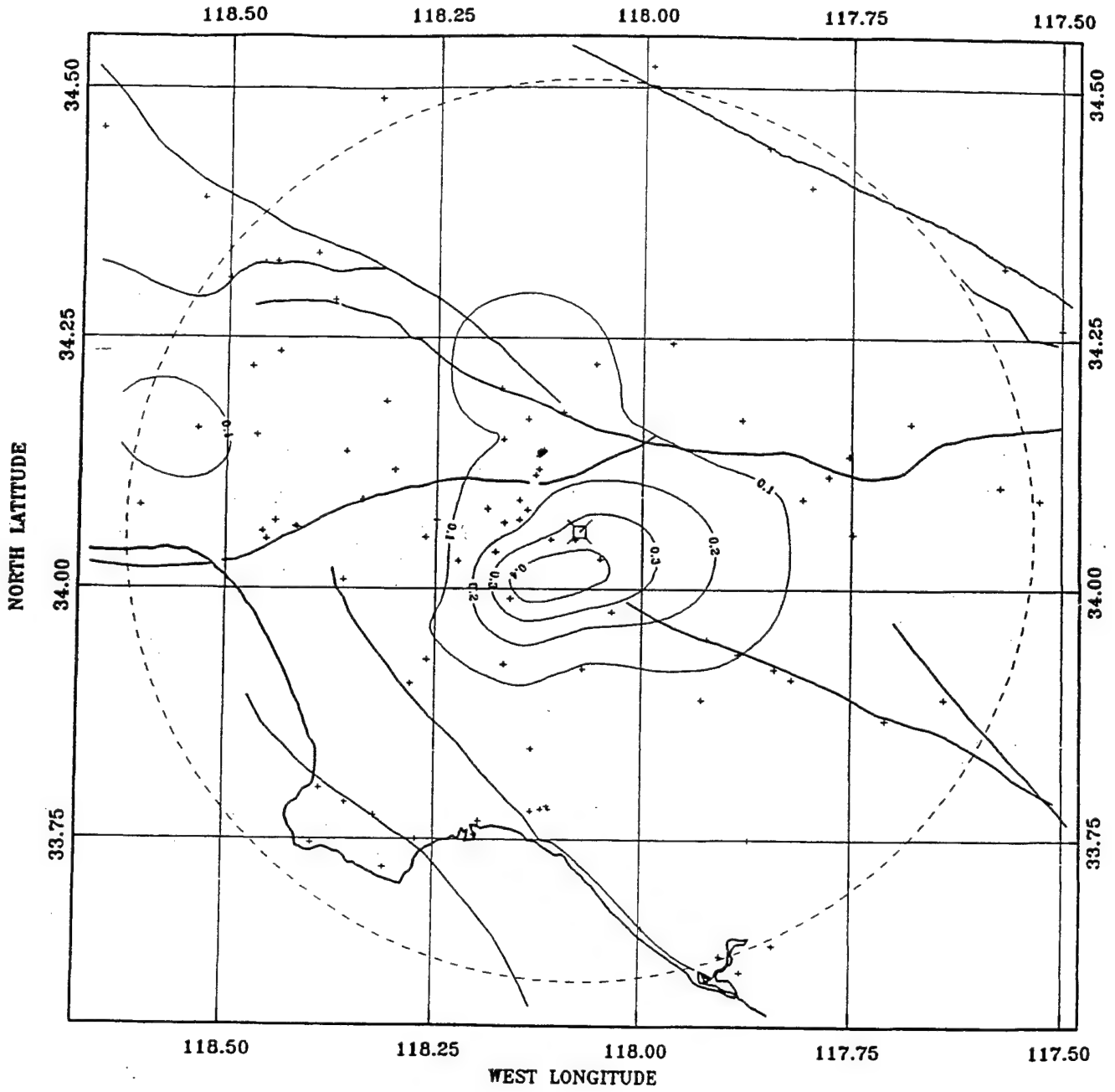
Stations – total: 348, with data: 343, without: 5, rejected: 0, in plot: 199

Map File: CALINE2.DAT
Command File: NR50HS.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: NRDGDIS.PRN
(Lambert conformal projection)
1995 MAY 28 18:34:38.81

Fig. NRDG-NHRP/Str-50-MAX (Col. AP)



Whittier Earthquake M=6.1 of October 1, 1987

Vertical NEHRP+Structure Corrected Acceleration, g

RADIUS OF CIRCLE IS 50 KM

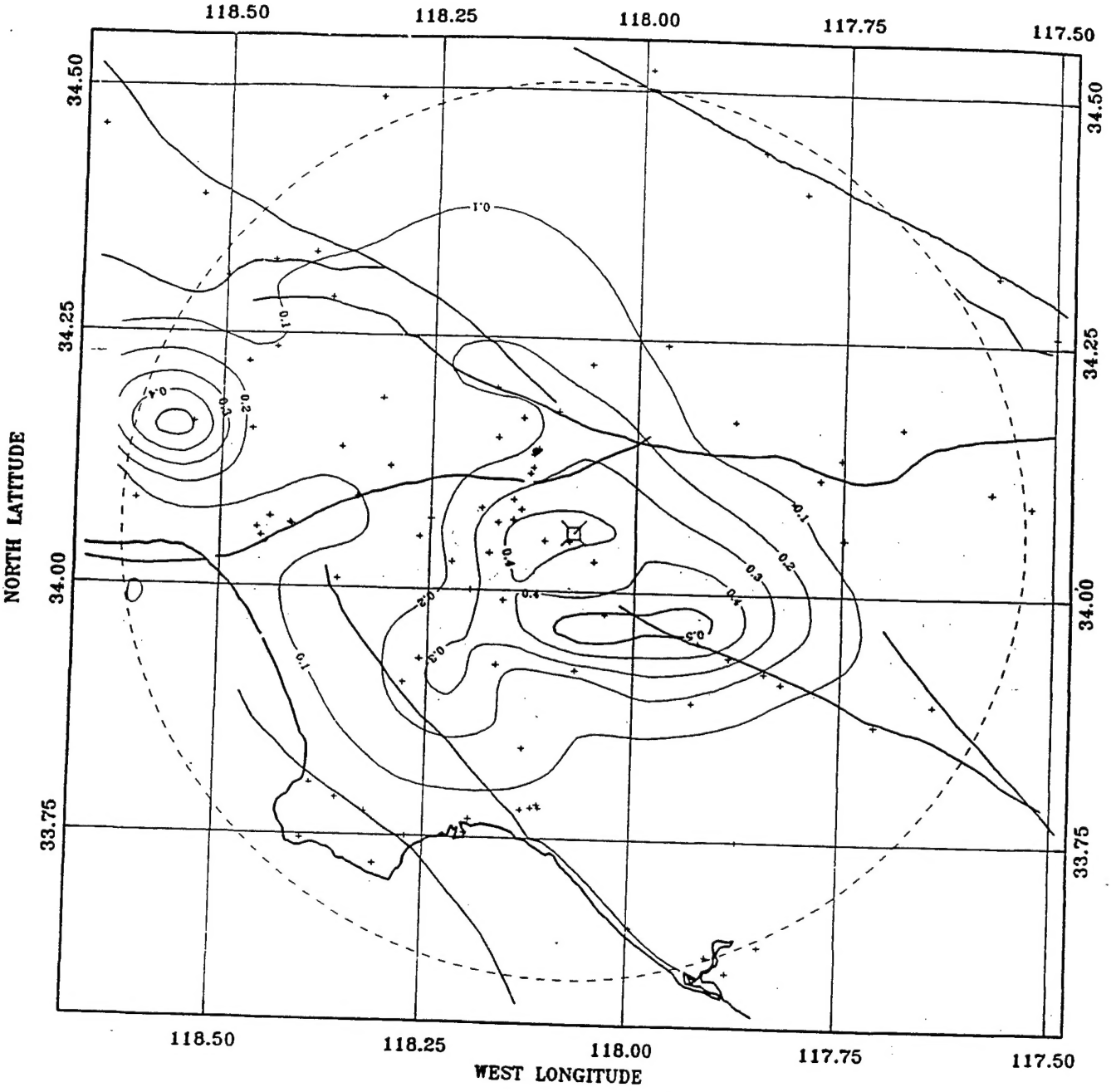
Stations – total: 184, with data: 184, without: 0, rejected: 0, in plot: 116

Map File: CALINE2.DAT
Command File: WH50VS.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: WHITDIS.PRN
(Lambert conformal projection)
1995 MAY 28 18:39:13.22

Fig. WHIT-NHRP/Str-50-V (Col. AN)



Whittier Earthquake M=6.1 of October 1, 1987

NEHRP+Structure Corrected Maximum Horizontal Acceleration, g

RADIUS OF CIRCLE IS 50 KM

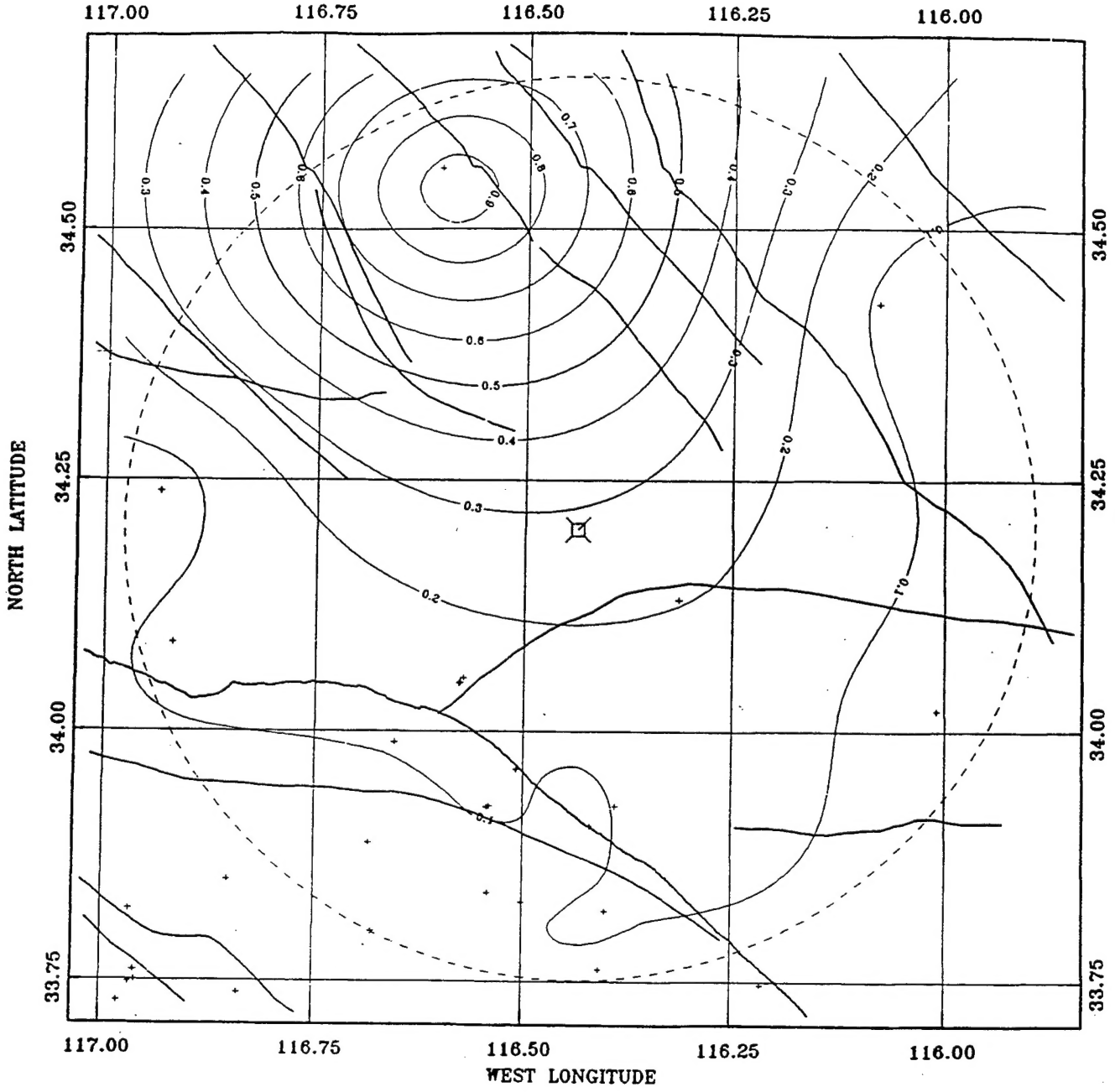
Stations – total: 184, with data: 184, without: 0, rejected: 0, in plot: 116

Map File: CALINE2.DAT
Command File: WH50HS.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: WHITDIS.PRN
(Lambert conformal projection)
1995 MAY 28 18:40:50.55

Fig. WHIT-NHRP/Str-50-MAX (Col. AP)



Landers Earthquake M=7.5 of June 28, 1992

Vertical NEHRP+Structure Corrected Acceleration, g

RADIUS OF CIRCLE IS 50 KM

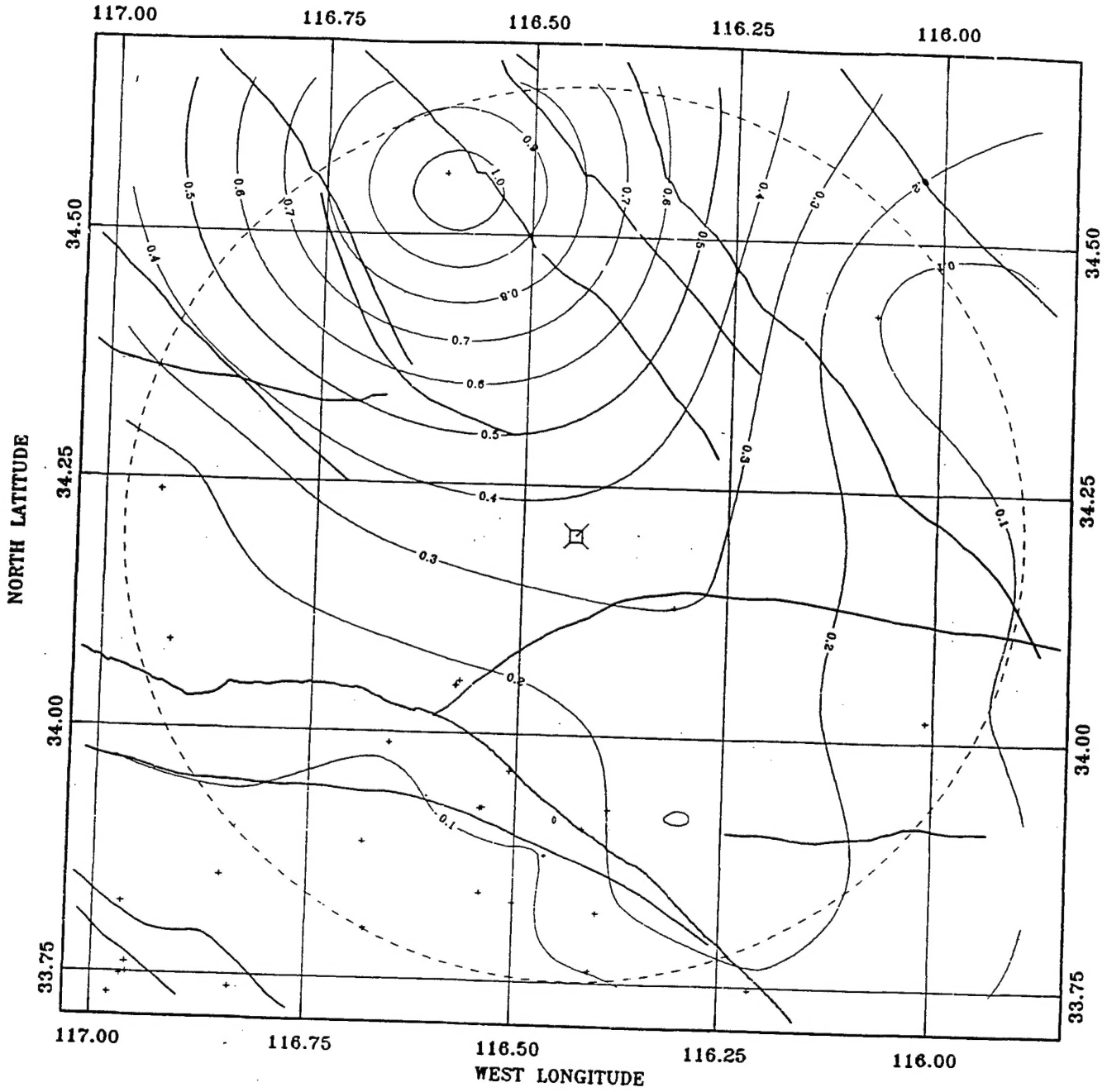
Stations – total: 162, with data: 162, without: 0, rejected: 0, in plot: 29

Map File: CALINE2.DAT
Command File: LN50VS.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: LANDDIS.PRN
(Lambert conformal projection)
1995 MAY 28 16:36:06.20

Fig. LAND-NHRP/Str-50-V (Col. AN)



Landers Earthquake M=7.5 of June 28, 1992

NEHRP+Structure Corrected Maximum Horizontal Acceleration, g

RADIUS OF CIRCLE IS 50 KM

Stations – total: 162, with data: 162, without: 0, rejected: 0, in plot: 29

Map File: CALINE2.DAT
Command File: LN50HS.GAC
Program: APGFAC2.75

Fault File: KANAMN.DAT

Station File: LANDDIS.PRN
(Lambert conformal projection)
1995 MAY 28 18:37:29.30

Fig. LAND-NHRP/Str-50-MAX (Col. AP)

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David J. Leeds

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David J. Leeds and Associates
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13. ABSTRACT ***(Maximum 200 words)***

Three datasets were analyzed and maps were prepared of near-source ground motions associated with the Whittier, Northridge, and Landers earthquakes in southern California. Vertical motions were enhanced in the near-source area of high-angle thrust faults at Whittier and Landers, similar to Northridge. Factors are provided for the enhancement in terms of site conditions. Distance factors were established with vertical-to-horizontal ratios. Areal patterns of earthquake ground motions were plotted with relation to known faults.

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